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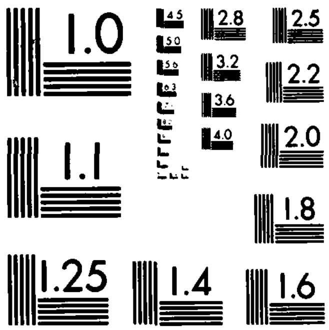

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INTEGRATED CUING REQUIREMENTS (ICR) STUDY: DEMONSTRATION DATA BASE AND USERS GUIDE

By

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NOTICE

This paper has been reviewed and is approved for publication.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The goal of the Integrated Cuing Requirements (ICR) Study was to consolidate and synthesize existing human sensory/perceptual data, principles and models in a manner which would make this information readily accessible and useful to the community of aircrew training device (ATD) design engineers.

There exists an extensive body of research literature on human perception which could potentially be of value in the specification, design, and evaluation of aircrew training devices. The data in this domain are distributed among numerous different publications and are written in the specialized terminology of perceptual psychology.

Item 20 (*Continued*)

Consequently, this information is not generally accessible to ATD engineers. The goal of the ICR study was to extract and consolidate the relevant data into an accessible format and to provide, where feasible, a synthesis of the literature which included recommendations relevant to equipment design. The intended output of this activity was (a) an ICR Data Base containing the available sensory/perceptual data in a form useful for specification and design purposes, and (b) an ICR Users Guide to facilitate access to the data by the ATD engineer.

Volume I of this technical paper presents the results of an Independent Feasibility Analysis and a subsequent Demonstration Study Evaluation, the purpose of which was to develop, test, and refine an approach to the ICR Study objectives discussed above. These activities constituted Phase I of the effort. The project was structured such that no decision on full-scale implementation of the approach (Phase II) would be made until an evaluation of Phase I had been completed. Volume II of this technical paper contains the Phase I Demonstration Data Base and Users Guide.

AFHRL Technical Paper 82-25(II)

July 1983

INTEGRATED CUING REQUIREMENTS (ICR) STUDY: DEMONSTRATION DATA BASE AND USERS GUIDE

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A

This publication is primarily a working paper.
It is published solely to document work performed.

PREFACE

This research supports the Air Combat Tactics and Training thrust of the Air Force Human Resources Laboratory (AFHRL). By describing an approach to consolidate existing sensory and perceptual data needed in the aircrew training device (ATD) design process, it directly supports the Engagement Simulation Technology subthrust of the Air Force Human Resources Laboratory, Operations Training Division (AFHRL/OT). The work was accomplished under contract by the Boeing Aerospace Company. This report consists of material written and submitted by the contractor, which has been reorganized and edited by the government. Invaluable editorial assistance in the final production of this volume was provided by Mr Kevin Hanford.

This research program was conceptualized, initiated, and managed by Dr. Ken Boff, under the former Advanced Systems Division of the Air Force Human Resources Laboratory. The program at Boeing Aerospace Company was managed by Mr. Wolfe Hebenstreit. The principal research activity was accomplished by Mr. Richard Farrell and Dr. Richard Barker.

Although the research program described herein was terminated, a reorganized approach to achieve the original project goals was initiated by the Air Force Aerospace Medical Research Laboratory, with the support of the Air Force Human Resources Laboratory. That program, entitled Integrated Perceptual Information for Designers (IPID), is managed by Dr. Ken Boff.

An extensive body of research data on human perception exists that can contribute to the specification, design, and evaluation of ATDs. These data are scattered among various publications and are written in the jargon of perceptual psychology. As a result, they are generally not useful to ATD engineers. The purpose of the Integrated Cuing Requirements (ICR) Study was to make these data useful. The approach was to extract and consolidate the relevant data into an accessible format and to provide a synthesis of the data into recommendations and implications directly relevant to ATD design.

The requirements imposed on an ATD vary with the portion of the flight task to be trained. An ATD suitable for landing is not necessarily adequate for air-to-air combat. Although training mission analysis was not within the scope of the ICR Study, the emphasis was on data relevant to the design of ATDs for training the most combat-critical portions of flight. Hence, data relevant to nap-of-the-earth flight or air-to-air combat receive more attention in the ICR Study than data relevant to takeoff and landing.

This document is a sample of the ICR Study output. It demonstrates the overall ICR Study approach applied to a small portion of the available data. The purpose of this sample or "demonstration" ICR output was to allow a field review by potential ICR users. The field review was intended to provide a diagnostic critique that would contribute to optimizing the format, accessibility, and content of the final version of ICR.

The ICR documentation is divided into two parts. These two parts are more fully explained in Section 1.0, INTRODUCTION TO ICR, and Section 2.0, HOW TO USE ICR.

(1) The Data Base contains the extracted research data, formatted for easy access and summarized in terms of recommendations or implications for ATD design. The Demonstration Data Base contains two sections of the twenty-nine planned. The organization was designed to facilitate expansion as additional topic areas were identified.

(2) The Users Guide provides means of accessing and using the data in the Data Base. Because access is so important in a document intended for engineering use, various Data Base entry methods are provided to meet the needs of individual users. These include tables of contents, an index, and several types of design-oriented analyses.

In addition to the entry methods in the Users Guide, access to related topics is provided within the Data Base by cross-references. Because this demonstration Data Base contains only two sections, most of the cross references are to sections that were not prepared. The reader should keep in mind the fact that this document was prepared as an example rather than as a completed product.

The two parts of the ICR documentation contain consecutively numbered sections as follows:

(1) Part I, the Users Guide, contains Sections 1.0 to 19.0.

(2) Part II, the Data Base, contains Sections 20.0 and above.

This consecutive section numbering and the overall structure of the ICR documentation was intended to facilitate future expansion and revision as new data became available. For example, to minimize the disruption caused by adding material, the pages, figures, and references are numbered within sections. Many section numbers have been reserved for the inclusion of topic areas beyond those listed in the Table of Contents. To facilitate review and revision within a section as new research data became available, the bibliographic sources were given for all data.

Only a small portion of the final ICR content is contained in this sample, specifically, Section 30.0, Judgements of Surface Orientation and Shape, and Section 33.0, Visually Induced Self-motion. Some idea of the scope of the complete ICR Study can be seen in several places. For example, both Tables of Contents list all the planned sections. In addition, the Expanded Contents describes the future content of each. Other sections in the Users Guide, while far from their final size, also provide some indication of the anticipated ICR data content.

The technology of ATDs changes rapidly. Hence, the goal was to keep ICR as independent as possible of specific hardware or software algorithms. Data application examples that refer to specific hardware or software algorithms were intended only as examples.

CONTENTS

*Sections 20.0 - 29.0, 31.0, 32.0, and 34.0 - 92.0+ were intentionally excluded from this volume. They were listed for information purposes relative to future intended efforts.

EXPANDED CONTENTS*

-------------------I C R U S E R S G U I D E------------------

* This table of contents provides the reader with a detailed listing all of the material in the Users Guide and the Data Base. It would eventually list every subsection. The contents listed for two sample Data Base Sections, 30.0 and 33.0, illustrate how the final product would appear. For the other Data Base sections, a brief summary of planned content is provided here as an indication of the material that will eventually be included.

3.0 HOW TO APPLY THE DATA BASE

- To assist the designer in the application of the material in the ICR Data Base, this section will in the future contain specific design examples. Each example will take a hypothetical design problem, such as specification of texture, and illustrate how the material in the Data Base contributes to the design solution.

4.0 PERCEPTUAL CUES USED IN FLIGHT

- A summary of published analyses and data on the perceptual cues that may be used during flight, with references to the location of any relevant data or recommendations in the ICR Data Base.

5.0 CUE CONFLICTS

- A listing of the conflicts that can occur between different ATD cues or between an ATD cue and the scene being portrayed. For example, such conflicts occur when the motion base cues do not match the visual system cues, and when the ATD visual scene content is impoverished relative to the real world.

(NOTE: These potential conflicts are primarily discussed in the ICR Data Base. This section simply allows the ICR user to become more easily aware of the discussions of potential conflicts in the Data Base by providing a place where they can be listed.)

6.0 DESIGN FEATURE ANALYSES

Access to the Data Base locations based on specific design features of ATD hardware and software.

7.0 DESIGN FEATURE CHECKLISTS

- Lists of questions designed to remind the user of the features to be considered in the design of an ATD to be used for any particular type of training.

8.0 MISSION-RELATED DESIGN FEATURE ANALYSES

- Consideration of the combat training mission to identify the types of perceptual data relevant to ATD design.

9.0 OVERVIEW OF EXPERIMENTAL METHODOLOGY

- A summary of the psychophysical and statistical considerations in ATD-related testing.

10.0 TUTORIALS

- A summary of basic background information to assist users who wish to have a better understanding of basic perceptual processes. This section will also help the user more fully understand the perceptual principles and models which form the basis for recommendations in the Data Base. Subsections will be included on visual, auditory, and vestibular functions.

11.0-16.0 RESERVED FOR FUTURE EXPANSION

17.0 ABBREVIATIONS, ACRONYMS AND UNITS

18.0 GLOSSARY

19.0 INDEX

20.0 INTRODUCTION TO ICR DATA BASE

- A brief introduction to the Data Base, repeating portions of Section 1.0, INTRODUCTION TO ICR.

Reference to Users Guide as a means of accessing Data Base.

(NOTE: This section would be needed when the Data Base reaches a size where it must be bound separately.)

21.0 VISUAL SYSTEM

- Brief summary of human visual system, introducing terms used in other sections such as "retina," "fovea," and "fixation point."

22.0 VISUAL DISCRIMINATION CAPACITY

- An observer's ability to judge what a visual stimulus should look like from memory is severely limited. This section will present guidelines about how closely the ATD visual display must match the real world in order for an observer to accept the stimulus as a correct match.

23.0 SPATIAL VISION AND TARGET ACQUISITION

- Visual acuity and visual contrast sensitivity function, foveally and peripherally.

- Target image features that affect spatial vision (shape, background, etc.)

    - Target acquisition model parameters relevant to ATD visual scene generation.

    - Perceptual requirements for target recognition and identification.

    - Discrimination of image features especially relevant to ATD specification, such as the amount of misalignment that will be noticeable in an image edge as it passes from one CRT to an adjacent CRT.

    - Relevant scene features such as glare, masking, and contrast effects.

24.0 SCENE LUMINANCE EFFECTS

    - Relationship between luminance and spatial, temporal, and color discrimination.

    - Tolerance for inequalities of luminance across the display.

    - Effects of glare.

- Different methods to measure scene luminance.

- Impact of scene luminance on visual ability.

25.0 COLOR

- Color dimensions (hue, saturation luminance).

- Methods of color specification, with emphasis on electronic display media and the simulation of real scenes.

- Color discrimination ability.

- Color contrast, color adaptation, etc.

- Effects of phosphors in a CRT.

26.0 EYE MOVEMENTS

- Types of movements. (Saccades, pursuit of smooth tracking, and nystagmus.)

- Saccadic suppression.

- Spatial and temporal characteristics of each type.

- Interactions with spatial resolution.

- Interaction with vestibular system.

27.0 IMAGE COLLIMATION/CONVERGENCE

- Acceptable values for comfortable, effective vision.

- Impacts of eye accommodation and convergence on visual perception (apparent object size, etc.)

- Interaction with chromatic aberrations.

28.0 VISUAL FIELD OF VIEW

- Normal visual field as function of target size and contrast, luminance, velocity, etc.

- Impact of field-of-view, or portion of field-of-view containing a scene, on aircraft piloting tasks.

29.0 STEREOPSIS

- Stereopsis as a cue to distance and depth.

- Acuity in static and dynamic scenes.

30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE (in sample Data Base)

30.1 Judgments of Dynamic Surface Orientation and Shape

30.1.1 Judgments of Dynamic Orientation
30.1.2 Judgments of Dynamic Shape
30.1.3 Texture Element Size and Density
30.1.4 Vertical Objects in a Dynamic Scene
30.1.5 Shadows and Reflections in a Dynamic Scene

30.2 Judgments of Static Surface Orientation and Shape

30.2.1 Judgments of Static Orientation
30.2.2 Judgments of Static Shape
30.2.3 Texture Element Size and Density
30.2.4 Vertical Objects in a Static Scene
30.2.4 Shadows and Reflections in a Static Scene

31.0 PERCEPTION OF DISTANCE/DEPTH AND SIZE

- Static and dynamic cues.
- Interaction between perceived size and perceived distance/depth

32.0 PERCEPTION OF DISTANCE/DEPTH AND SIZE

- Real object motion versus motion resulting from intermittent stimulation.

- Scene motion versus object motion versus self-motion; figure and ground effects.

- Visual artifacts due to aliasing in a moving scene (image doubling, strobing, etc.)

- Minimum visible motions.

33.0 VISUALLY INDUCED SELF-MOTION (in sample Data Base)

33.1 Test Configurations

33.2 Image Content and Quality

33.3 Location and Extent of Area Containing Image Detail

33.4 Image Distance

33.5 Conflict Between Moving and Non-Moving Image Details

33.6 Latency of Self-Motion

34.0 CHANGES IN VISION DUE TO G-LOADING

- Differential scene fading, etc.

35.0-44.0 RESERVED FOR FUTURE EXPANSION

45.0 AUDITORY SYSTEM

46.0 DISCRIMINATION OF SIMPLE SOUNDS

47.0 DISCRIMINATION OF COMPLEX SOUNDS

48.0 TEMPORAL LOCALIZATION

49.0 SPATIAL LOCALIZATION

50.0 AUDITORY INDUCTION OF SELF-MOTION

51.0 INFORMATION (CHANNEL) CAPACITY

52.0-60.0 RESERVED FOR FUTURE EXPANSION

61.0 VESTIBULAR SYSTEM

62.0 PERCEPTION OF ANGULAR MOTION

63.0 PERCEPTION OF LINEAR MOTION

64.0 PERCEPTION OF POSITION AND ORIENTATION

65.0 PERCEPTION OF MULTI-AXIS MOTION

66.0-75.0 RESERVED FOR FUTURE EXPANSION

76.0 FORCE CUING OF MOTION (G-seats and G-suits)

77.0-90.0 RESERVED FOR FUTURE EXPANSION

91.0 VISUAL-VESTIBULAR INTERACTIONS

92.0+ OPEN FOR FUTURE EXPANSION

SECTION 1.0 INTRODUCTION TO ICR

PAGE

SECTION CONTENTS

SECTION 1.0 INTRODUCTION TO ICR

1.1 OBJECTIVES

The purpose of the ICR documentation is to make the existing data on human perception relevant to aircrew training device (ATD) specification, design or evaluation available to ATD engineers in an easily accessible manner. Since this actually entails two goals, the documentation is divided into two parts:

1) The ICR Data Base contains the relevant data on human perception, formatted for easy use and summarized into recommendations relevant to ATD design. (The organization of the data and recommendations in the Data Base is described in detail in Section 1.5)

2) The ICR Users Guide provides several means of accessing the data in the Data Base and illustrates how to apply these data after they are accessed. (The different methods of access are described in detail in Section 2.0)

1.2 SCOPE

The ICR Data Base is intended to provide information on all the topics dealing with human perception that might be of use to the ATD engineer. The demonstration Data Base you are reading contains two sections, 30.0-JUDGMENTS OF SURFACE ORIENTATION AND SHAPE, and 33.0-VISUALLY INDUCED SELF-MOTION. The CONTENTS indicate the additional sections currently planned, and the EXPANDED CONTENTS provide a description of the type of data to be included in each. Some of the section numbers have been left unassigned for future expansion.

SECTION 1.0 INTRODUCTION TO ICR

1.3 DATA BASE DEVELOPMENT

The preparation of the sample Data Base involved a series of steps designed to ensure that the data were maximally useful to the ATD engineer and were scientifically valid. These steps, which were followed in preparing the remainder of the Data Base sections, included:

1) Identification of the data topics relevant to ATD specification, design or evaluation. This step utilized the experience of ATD engineers and of scientists involved with human perception who had participated in ATD specification or evaluation.

2) Selection from the list of Step (1) data topics for incorporation into the sample Data Base.

3) Collection and review of literature describing research on these sample topics.

4) Extraction from this literature of the research data relevant to ATD design.

5) Formatting of these data for easy interpretation by ATD engineers. (This is the form in which data appear in the Data Base.)

6) Summarization of these data into recommendations applicable to ATD specification, design or evaluation. (These also appear in the Data Base.)

1.4 ORGANIZATION OF ICR DOCUMENTATION

The ICR documentation is divided into two parts, the Users Guide and the Data Base. Section numbering is consecutive across the two parts. Sections 1.0 to 19.0 are in the Users Guide. Sections 20.0 and above are in the Data Base. The use of different section numbers in the Users Guide and the Data Base makes it possible to refer the reader to a particular section without the necessity of indicating whether it is in the Users Guide or in the Data Base. In addition, it facilitates binding the Users Guide and the Data Base in a single document, as in this sample, and later binding the two separately when the Data Base becomes larger.

1.4.1 USERS GUIDE

The ICR Users Guide is designed to help the user access and apply the information in the ICR Data Base. To achieve this purpose, it contains the following types of material:

1) Entry methods designed to allow users with diverse backgrounds and interests to access the information in the Data Base. (Access methods are discussed at length in Section 2.0.)

- Contents
- Expanded Contents
- Index (Section 19.0)
- Cue Conflicts (Section 5.0)
- Design Feature Analyses (Section 6.0)
- Design Feature Checklists (Section 7.0)
- Mission-Related Design Feature Analyses (Section 8.0)
- How to Access the Data Base (Section 2.0)

2) Background information outside the scope of the Data Base but which may be helpful interpreting or applying the data in the Data Base.

- How to Apply the Data Base (Section 3.0)
- Perceptual Cues Used in Flight (Section 4.0)
- Tutorials (Section 10.0)
- Overview of Experimental Methodology (Section 9.0)
- Abbreviations, Acronyms and Units (Section 17.0)
- Glossary (Section 18.0)

1.4.2 DATA BASE

The sections in the ICR Data Base are organized according to sensory modality. That is:

- Vision (Sections 21.0 through 44.0)
- Audition (Section 45.0 through 60.0)
- Vestibular Function (Section 61.0 through 90.0)
- Interaction Between Modalities (Section 91.0+)

1.5 DATA ORGANIZATION

Material within the ICR Data Base is organized in a hierarchical fashion to facilitate engineering application. Starting at the bottom of the hierarchy, most of the individual experiments or groupings of experiments are summarized in figures. The organization of material within a figure is discussed in Section 1.5.1.

At the other extreme of the hierarchy, the implications of the experimental data for ATD design are summarized in the form of "RECOMMENDATIONS." The recommendations are connected to the experimental data by "SUPPORTING ANALYSES." Modifying the recommendations, or placing restrictions on their applicability, are the "LIMITATIONS OF THE RECOMMENDATIONS." The organization of the recommendations, supporting analyses, and limitations is discussed in Section 1.5.2.

1.5.1 ORGANIZATION WITHIN FIGURES

Most figures are representative of several related experiments. A few provide background information and do not contain experimental data.

Figures that contain experimental data consist of from two to four parts:

1) IMPLICATION

- The implication of the data for ATD design is presented first.

2) REPRESENTATIVE STUDY

- This is the experiment summarized in the figure to show the type of support that an implication has. In general, the representative study is one of several studies that support the implication. In some cases the term "representative" is not used because the study is the only one that has addressed that particular issue. Section 30.0 contains mostly "representative

1.5.1 ORGANIZATION WITHIN FIGURES (CONTINUED)

studies" because it involves an area in which there are many studies, and the studies summarized are illustrative of the several that pertain to each implication. Section 33.0 involves an area in which there has been much less research. As a result, the studies presented are almost all of the relevant literature and the term "representative" is not appropriate.

- A subsection titled LIMITATIONS is included within the experiment summary. It presents possible reservations about applying the implication given earlier in the figure to an ATD. This is intended to help the user assess the experimental context of the implication, and evaluate its relevance to the user's particular design problem.

3) SUPPORTING LITERATURE (where appropriate)

- When there are several studies that directly support the implication, they are listed here. In cases where the studies presented in the figures exhaustively cover the available literature, this section is inappropriate and has been omitted.

4) CROSS-REFERENCES (where appropriate)

- Cross-references are used to indicate relationships between different sections in the Data Base.

1.5.2 ORGANIZATION OF THE SECTIONS

The organization of material within a section will vary slightly depending on the complexity and inherent structure of that technical area. Section 30.0, JUDGMENT OF SURFACE ORIENTATION AND SHAPE, provides a good example because it covers a complex area that has been extensively researched for many decades. The construction of sections from subsections and figures is graphically illustrated in Figure 1.5.2-1.

- Starting at the right in Figure 1.5.2-1, the figures in Section 30.0 summarize representative research studies and their implications for ATD engineering.
- Moving to the left in Figure 1.5.2-1, the implications of the data are integrated and summarized to form design recommendations at the next higher subsection level.
- The implications in the subsections are integrated to form recommendations at the next higher level of subsection (when more than one level of subsection exists).
- The limitations of the recommendations are integrated and brought forward, as well as a brief supporting analysis of both the recommendations and limitations. The supporting analysis is given to allow the designer to assess the usefulness of the recommendation without having to go all of the figures that give support to that recommendation, and to give the rationale for the manner in which the recommendation were integrated.
- Not all of the recommendations were integrated or combined. Some of the recommendations were important enough in and of themselves that integration with other recommendations would have obscured their significance. These recommendations were brought forward without change.

30.0
JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

RECOMMENDATIONS

1) Do not apply recommendations about a static scene to a dynamic scene, or vice versa, unless specifically recommended.

30.1
JUDGEMENTS OF DYNAMIC SURFACE ORIENTATION AND SHAPE

RECOMMENDATIONS

1) Do not apply recommendations about a static scene to a dynamic scene or vice versa unless specifically recommended.

30.2
JUDGEMENTS OF STATIC SURFACE ORIENTATION AND SHAPE

RECOMMENDATIONS

1) Do not apply recommendations about a static scene to a dynamic scene, or vice versa, unless specifically recommended.

SECTION 30.2.1
JUDGEMENTS OF STATIC ORIENTATION

RECOMMENDATIONS

1) Texture patterns should have uniform size and spacing.

SECTION 30.2.2
JUDGEMENTS OF STATIC SHAPE

RECOMMENDATIONS

1) Assume that when edges intersect they are judged as intersecting *at right angles* even if they must be mentally rotated out of their intended orientation to be seen that way.

SECTION 30.2.3
TEXTURE ELEMENT SIZE AND DENSITY

RECOMMENDATION

1) Use an intermediate size and spacing of texture elements.

Figure 30.2.1-1 Judged Slant of Regular and Irregular Texture. IMPLICATION: Regular texture gives more slant information than irregular texture in a static scene.

Figure 30.2.1-2 Judged Slant of Parallel Lines IMPLICATIONS: Parallel lines along line of sight give more slant information than parallel lines across the line of sight.

Figure 30.2.1-3 Judged Slant of Texture with Elements Changing in (1) Size and Shape or (2) Distribution Density IMPLICATION: The size and shape of texture elements give more slant information than the relative density of the texture.

Figure 1.0-1 Structure of Material in Section 30.0. Research data and implications are organized into successively more general recommendations.

1.5.2 ORGANIZATION OF THE SECTION FIGURES (CONTINUED)

- There is a high level of redundancy of recommendations between the different levels in the section-subsection hierarchy. This was done to allow the user to gain all of the recommendation at whatever level of detail he entered the Data Base. Otherwise, if the user entered the Data Base at the higher section level, he would have to search all the lower sections, subsections, and figures to find all of the recommendations. Since all of the significant recommendations are presented more than once, it will assure that (1) the designer will gain all of the relevant information, and that (2) this can be done with a minimum of searching.

- In cases where there is insufficient research to support a recommendation, or only anecdotal evidence exists, a professional opinion is given with the limitation noted that there is no supporting evidence. A brief supporting analysis is given to indicate the reasoning that lead to the opinion. Professional opinions are given in the hope that (1) they will be of assistance to the designer when a design question must be answered in the absence of sufficient data and that (2) research will eventually be conducted to provide a better basis for a recommendation.

SECTION CONTENTS

SECTION 2.0 HOW TO ACCESS THE DATA BASE

Several methods of entry are available for accessing the data in the ICR Data Base. These are summarized in Section 2.2 and described in detail in Sections 2.2.1 through 2.2.4.

ACCESS TECHNIQUES

Basis of Approach	Suggested Access Method	Described in Section	Located on Page
GENERAL TOPIC	CONTENTS	2.2.1.1	iv
	EXPANDED	2.2.1.2	vi
SPECIFIC SUBJECT	SUBJECT INDEX	2.2.2	19.0-1
DESIGN FEATURE	DESIGN ANALYSIS	2.2.3.1	6.0-1
	DESIGN CHECKLIST	2.2.3.2	7.0-1
MISSION	MISSION ANALYSIS	2.2.4	8.0-1

NOTE:

When a user fails to find the desired information in any type of handbook, the majority of times it is because the user entered the handbook's table of contents or index with a "key word" that was too specific.

If an attempt to find the required information in the Data Base fails, re-enter the Users Guide with a more general approach.

SECTION 2.0 HOW TO ACCESS THE DATA BASE

These entry methods have another function in addition to data access. Several, particularly those based on ATD design features or missions, will assist the user in formulating a design problem and in identifying the factors involved in reaching a design solution.

A third function of some entry methods is to illustrate the organizational structure of the perceptual information within each Data Base section. As Section 2.1 points out, this allows the user to enter the Data Base at the level appropriate for a particular design question.

2.1 LEVEL OF DATA BASE ACCESS

In some sections of the Data Base, primarily Section 30.0 in this sample, the data are organized into a hierarchical structure. At the lowest level are specific details, with more general details at a higher level of organization. Some of the entry methods, particularly in the extended version of the table of contents, and to some extent the index, illustrate this hierarchical structure and allow entry at the level appropriate to the user's design problem.

Referring to Section 30.0, each subsection contains some redundant information. The Expanded Table of Contents can be used to enter the Data Base at the level that is most appropriate to a particular design question. For example, if the Data Base is entered at Figure 30.1.1-1 (Judged Slant of a Dynamic Surface with Regular and Irregular Texture) it will not be necessary to read the material giving the precursor information on this topic such as that at the begining of Section 30.0 (Judgments of Surface Orientation and Shape), or 30.1 (Judgments of Dynamic Surface Orientation and Shape), or even in 30.1.1 (Judgments of Dynamic Orientation), although it may be useful. Each section and subsection contains the recommendation and limitations which apply to those recommendations necessary to evaluate the data in that section. (The Data Base organization is also described in Section 1.5.2.)

SECTION 2.0 HOW TO ACCESS THE DATA BASE

2.1 LEVEL OF DATA BASE ACCESS (CONTINUED)

Within a subsection of the Data Base, there are many levels of data summaries that can be used.

1) Recommendations - Recommendations are intended to be directly usable to the designer in making design decisions. Recommendations exist at several different levels of specificity. The deeper he goes in the section/subsection hierarchy, the more specific the recommendations tend to become. They can be used as an input to a design decision without recourse to the detailed data from which the recommendations were derived.

2) Supporting Data - Examples of the types of data from which the recommedations were derived are included to allow the designer to assess the applicability of the recommendation to a specific design need. If the designer is in doubt about the context in which the recommendation was intended to be applied, the example of the supporting data that is included will help the designer make a decision. In cases where there is little or no evidence to support a recommendation, a professional opinion is given with the notation that there are no supporting data.

3) References to the Original Literature - It is not expected that the designer will be able to review all of the literature on a topic in order to assess a recommendation. However, the situation could arise in which the designer wishes to have an in-depth understanding of a subject, and the original experimental literature has been referenced to make this possible.

SECTION 2.0 HOW TO ACCESS THE DATA BASE

2.2 METHODS OF ACCESS

The methods of access to the ICR Data Base include two tables of contents, an index, and analyses and checklists based on ATD design features and training missions. These are summarized in Figure 2.2-1, and discussed more fully in 2.2.1, and discussed more fully in Sections 2.2.1 through 2.2.4.

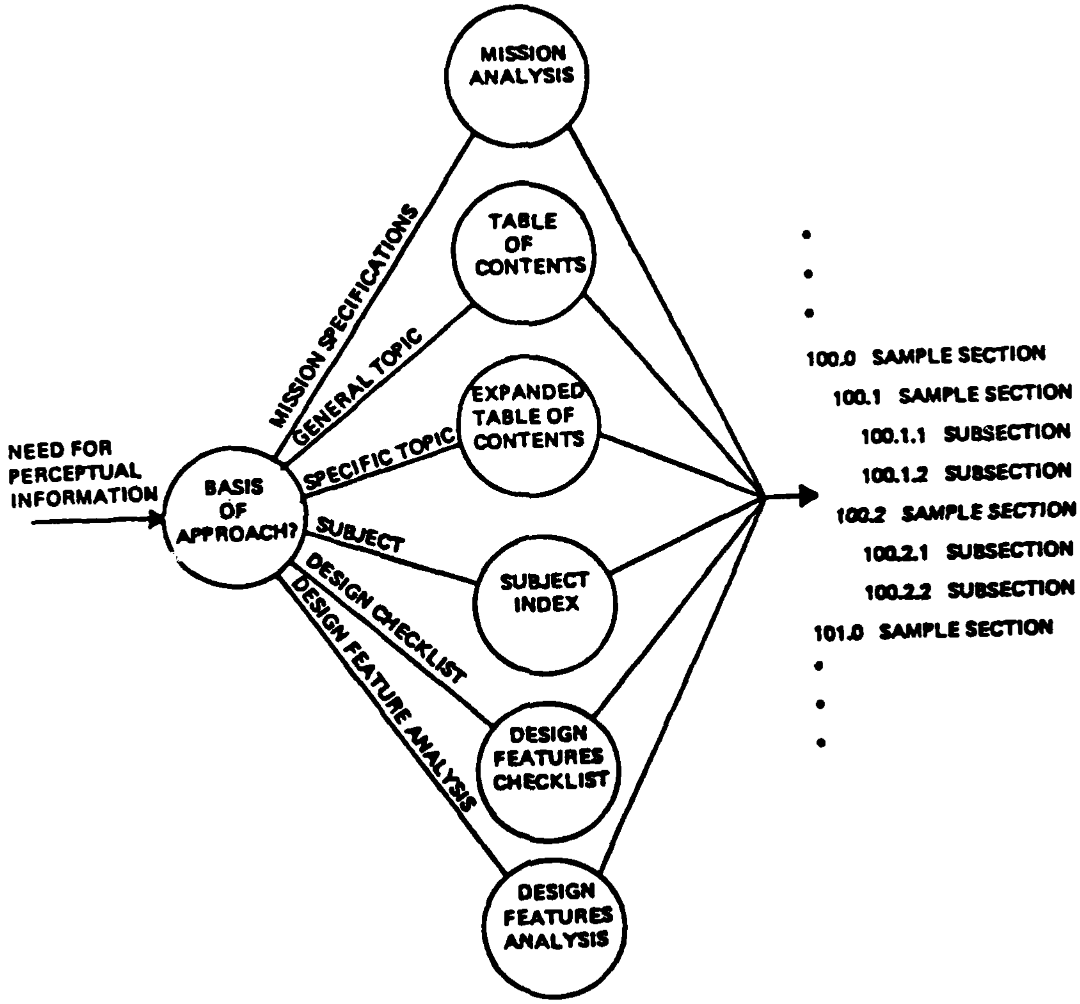


Figure 2.2-1 ICR Data Base Access

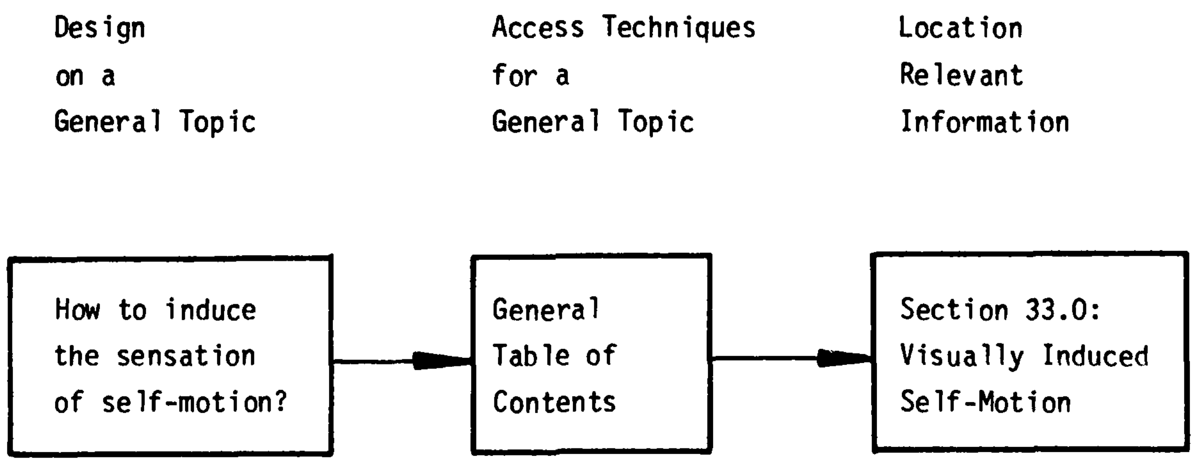
SECTION 2.0 HOW TO ACCESS THE DATA BASE

2.2.1 TABLES OF CONTENTS

Two tables of contents have been included. These are a summary level Table of Contents and an Expanded Table of Contents that includes a detailed listing of the subsections.

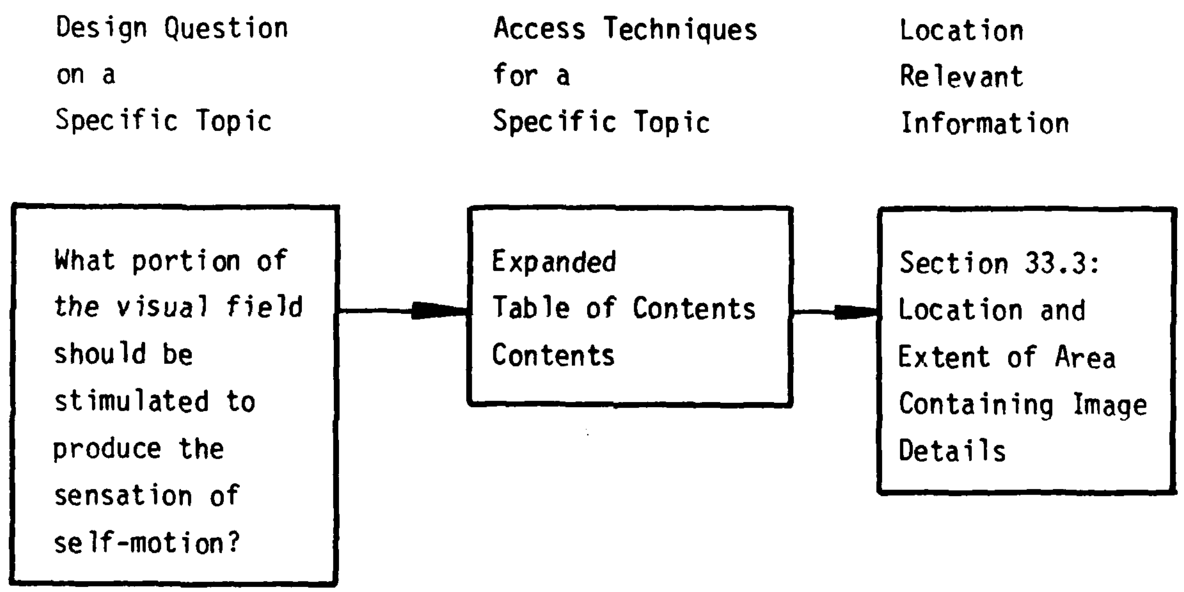
2.2.1.1 TABLE OF CONTENTS

A summary level table of contents is used to acquaint the user with the overall organization of the Data Base and the general content of the sections. If information is needed about a broad topic, or if a general familiarization with the contents is needed, this is the suggested section to consult. For example, if the designer is concerned about how to use the visual scene to give the trainee a sensation of movement even though the ATD is stationary, the table of contents is used to locate section 33.0, VISUALLY INDUCED SELF-MOTION.



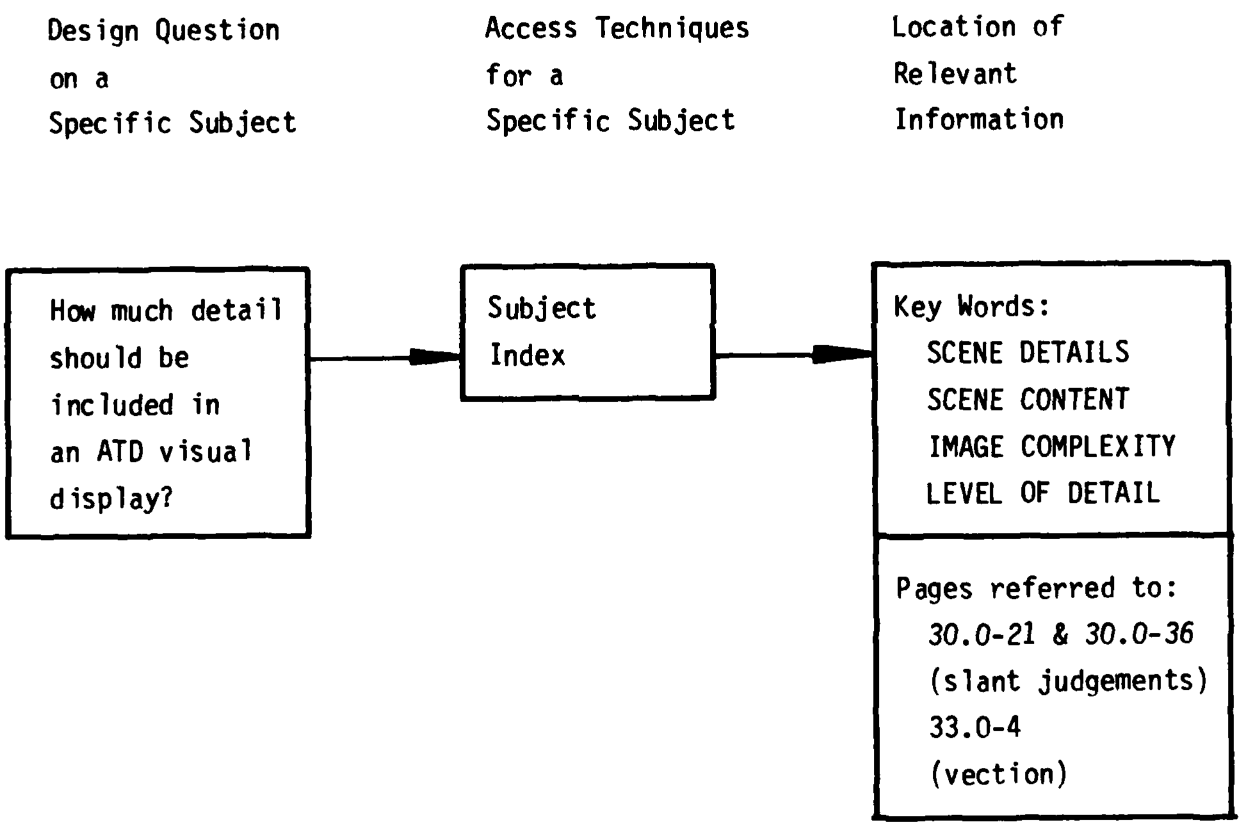
2.2.1.2 EXPANDED TABLE OF CONTENTS

The Expanded Table of Contents allows the user to enter the Data Base to find information on a specific topic. The titles of the subsections within a section will lead the user to the section or subsection that both contains the needed information and has the desired level of specificity. If specific data are needed, the structure of the subsections in the Expanded Table of Contents will direct the user to the subsection that contains the required information. For example, if the designer wants to know which portion of the visual field is most effective for inducing self-motion, the Expanded Table of Contents will direct the designer first to Section 33.0, VISUALLY INDUCED SELF-MOTION, and from there to Section 33.3, LOCATION AND EXTENT OF AREA CONTAINING IMAGE DETAILS.



2.2.2 SUBJECT INDEX (SECTION 19.0)

The subject index allows the user to enter the Data Base to find information on a specific subject. For example, if the designer is concerned about the amount of detail that should be included in a scene, the subject index will direct the designer to at least three places: (1) Page 30.0-21, Section 30.1.3, Optimal Size and Density of Texture Elements for Slant Judgements in a Dynamic Scene; (2) Page 30.0-36, Section 30.2.3, Optimal Size and Density of Texture Elements for Slant Judgements in a Static Scene; and (3) Page 33.0-4, Section 33.2, Image Content and Details for Visually Induced Self-Motion.



2.2.3 DESIGN FEATURES

These entry techniques are intended to acquaint the designer with the perceptual aspects of some of the ATD hardware design issues. They are not intended to tie the Data Base or Users Guide to any specific hardware or technology.

2.2.3.1 DESIGN FEATURES ANALYSIS (SECTION 6.0)

This section contains information on the perceptual aspects of various ATD design features. For example, if the designer seeks information on the effects of allowing the raster lines in a CRT used as an ATD display to be visible, this section would lead to (among other sections): (1) Section 23.0, (for information about when the raster lines become visible); (2) Section 33.5, (on the effects of stationary scene details on visually induced self-motion); and (3) Section 30.0 (on the effects of a texture gradient that is not perspectively correct).

Design Question about a Design Feature		Access Techniques for a Design Feature		Location of Relevant Information
What are the perceptual effects of a visible raster line?	→	Design Feature Analysis	→	Sections: 23.__ on accommodation 30.0 on texture and slant perception 33.5 on the effects of stationary scene details on vection

2.2.3.2 DESIGN FEATURES CHECKLIST (SECTION 7.0)

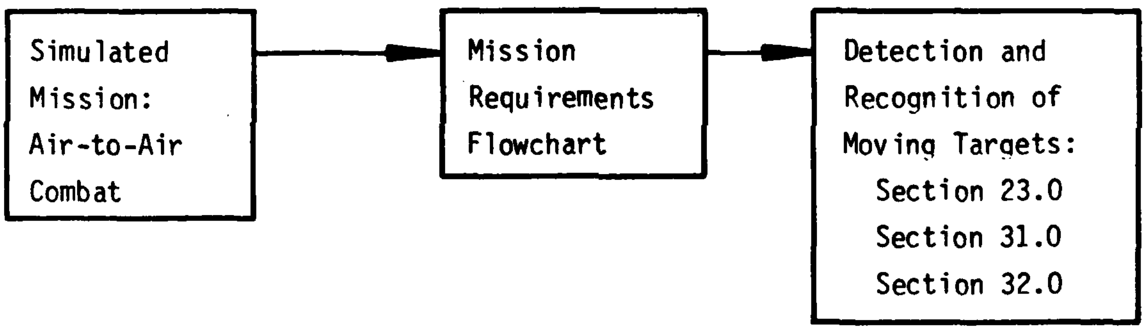
If the designer does not have a specific design issue in mind but only wants to know what design issues to consider, the Design Features Checklist provides a method for insuring that the designer has considered all of the relevant design issues. The Design Checklist would make the designer consider the detrimental effects of a visible raster line, even if he had not been aware of (and hence had not looked for) such effects. The designer can then use this information, in conjunction with his professional experience, to assist in the design process.

Design Question "Has all relevant perceptual information been considered?"	Access Techniques for an Overall Check For Completeness	Relevant Information
No recognized need for perceptual information. Need for method of insuring that all perceptual information has been considered.	→ Design Features Checklist →	Must consider effects of visible raster lines. Utilize the Design Features Checklist or any of the other access techniques.

2.2.4 MISSION ANALYSIS (SECTION 8.0)

This section allows the designer to locate the data most relevant to simulating specific mission elements. For example, if the mission is air-to-air combat, this section will refer the designer to data about the detection and recognition of moving targets (amont other topics relevant to air-to-air combat). Data about the detection and recognition of moving targets is contained in: (1) Section 23.__ (on visual acuity); (2) Section 31.__ (on the accuracy of distance judgements); and (3) Section 32.__, (on the perception of moving targets.

Design Question about Mission Requirements	Access Techniques for Mission Requirements	Location of Relevant Information



SECTION 3.0 HOW TO APPLY THE DATA BASE

The Data Base developed during the ICR Study is intended to provide the ATD designer with an additional design resource. However, it is not a set of carved-in-stone design rules that replaces engineering judgement. Instead, it provides access to perceptual data that can be used by the designer in conjunction with knowledge of state-of-the-art ATD capability, past approaches, cost/benefit tradeoffs, and professional judgement, to obtain a more effective ATD. Figure 3.0-1 illustrates how the designer is the essential component in the utilization of these resources.

To assist the designer in the application of the material in the ICR Data Base, this section will in the future contain specific design examples. Each example will take a hypothetical design problem, such as specification of texture, and illustrate how the material in the Data Base contributes to the design solution.

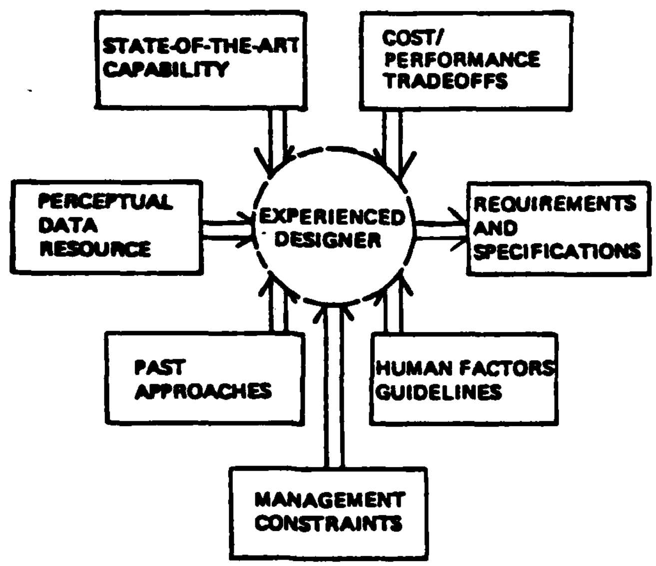


Figure 3.0-1 Relation of Perceptual Data to the Design Process

SECTION 4.0 CUES USED IN FLIGHT

Knowledge of what perceptual cues are used during fight is important to the ATD design process because these are in general the cues that should be provided by the ATD to obtain effective training. The requirements imposed on an ATD derive directly from these cues.

The perceptual cues used during flight are not well established but have received some analytical attention. Determination of these cues is beyond the scope of the ICR Study, but to make the information that has been published on this important topic more accessible to the ATD engineer, it will be summarized here. This summary will cover material such as the study by Meyer, Laveson, Pape, and Edwards, <u>Development and Application of a Task Taxonomy for Tactical Flying</u> (AFHRL-TR-78-42).

SECTION 5.0 CUE CONFLICTS

This section will contain a listing of the conflicts that can occur between different ATD cues or between an ATD cue and the scene being portrayed. For example, such conflicts occur when the motion base cues do not match the visual system cues, and when the ATD visual scene content is impoverished relative to the real world.

(NOTE: These potential conflicts are primarily discussed in the ICR Data Base. This section simply allows the ICR user to become more easily aware of the discussions of potential conflicts in the Data Base by providing a place where they can be listed.)

SECTION 6.0 DESIGN FEATURE ANALYSES

This section will provide access to the Data Base in terms of specific hardware or software features such as display field-of-view, CRT raster line visibility, and spatial distribution of CIG texture elements. These features will be organized according to the type of hardware involved. Within each feature, each reference to a location in the Data Base will include a brief statement of why the material in that section is relevant.

SECTION 7.0 DESIGN FEATURE CHECKLIST

This section will contain lists of questions to help the designer identify the Data Base material relevant to an ATD intended for a particular purpose. The organization of the questions will be similar to Section 8.0 in that it will be user-oriented, while the questions themselves will be hardware-oriented as in Section 6.0. For example, the list of questions for an ATD to train air-to-air combat will include questions concerning display resolution and method of portraying a distant aircraft.

SECTION 8.0 MISSION-RELATED DESIGN FEATURE ANALYSES

The requirements imposed on an ATD vary with the type of flight task to be trained. For example, a visual scene display for training high altitude air-to-air combat requires higher image resolution but not as many scene edges as one for training nap-of-the-earth flight. Similarly, an ATD adequate for landing training is not necessarily adequate for combat training.

This section provides access to the data in the ICR Data Base in terms of the type of flight task to be trained. This is not intended as a definitive analysis of flight training requirements, since this is outside the scope of the ICR Study. Rather, it is provided to help the user who needs to consider ATD design from one of these points of view to identify the topic areas that should be considered, and to find where each is treated in the ICR Data Base.

The charts that follow in this section are organized around the concept of part-task training. In this way, it is possible to identify the ATD design features that derive from the requirement to train each portion of the flight task. Whether these are implemented in several different part-task trainers or are combined into a single more complex device that provides all of these features is the prerogative of the ATD engineer.

This section presently contains three charts. As the Data Base is completed, these will undergo revision and expansion and additional charts will be prepared.

1) Figure 8.0-1 shows a functional breakdown of combat training for fixed-wing aircrews and identifies the subsequent charts that treat data categories relevant to each portion of the flight task.

2) Figure 8.0-2 summarizes data categories for training nap-of-the-earth flight.

3) Figure 8.0-3 provides the beginning of a similar summary for interaction with distant aircraft during air-to-air combat. It illustrates how branches appear in the chart when there are several hardware approaches to one problem, in this case the problem of providing a high-resolution insert to portray the distant aircraft adequately. (This type of hardware-oriented analysis appears primarily in Section 6.0)

When completed, the references to Data Base locations in these charts will be as specific as possible. Hence, the user will not be referred to Section 23.2 when only Section 23.2.1 is relevant. When the charts in this sample make reference to Data Base sections not yet completed, this specificity is illustrated by the use of a number such as 23._, rather than just 23.0. In those cases where an entire section is relevant, this is indicated by an entry ending in a zero, such as 23.0.

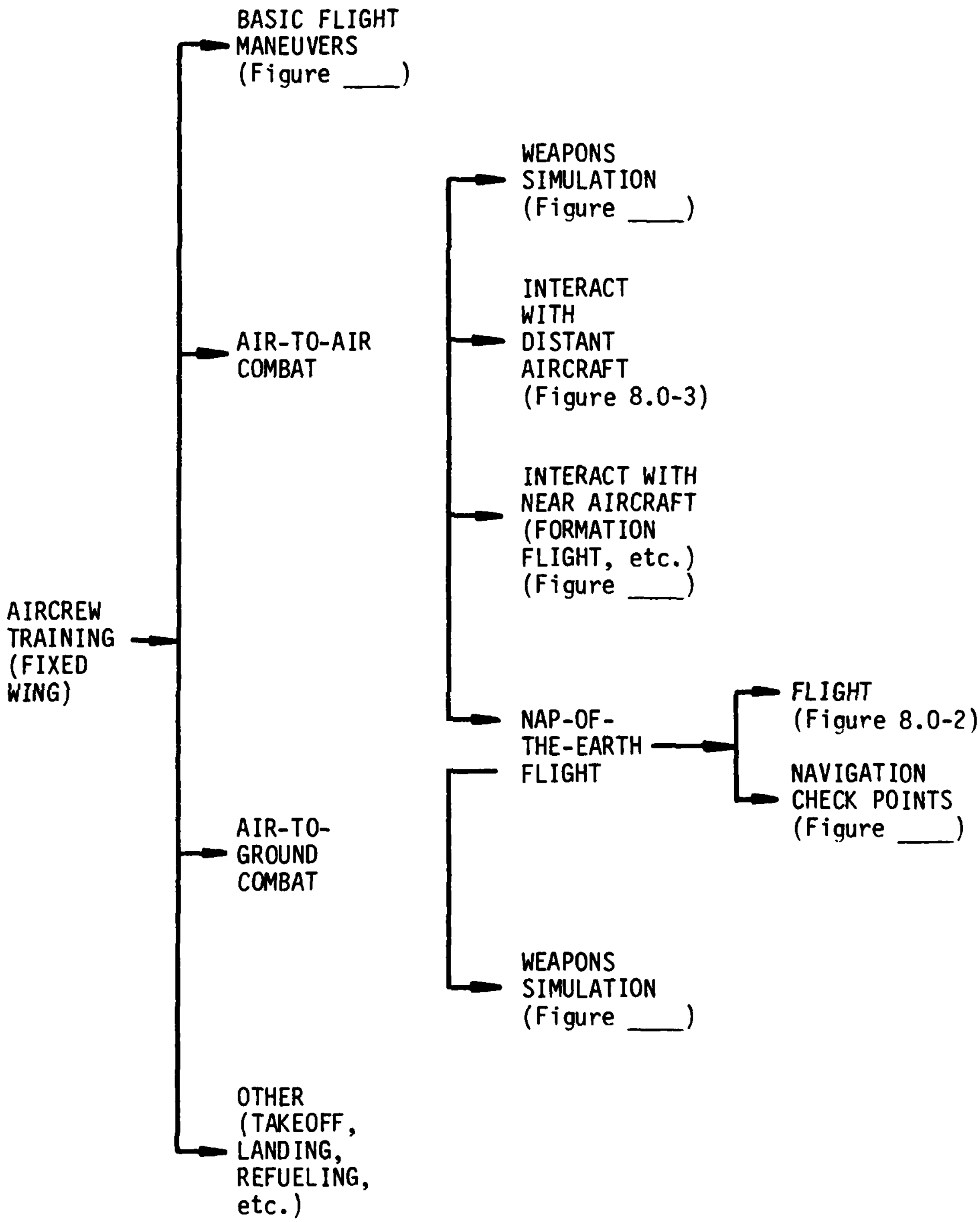


Figure 8.0-1 Fixed-Wing Aircrew Functions

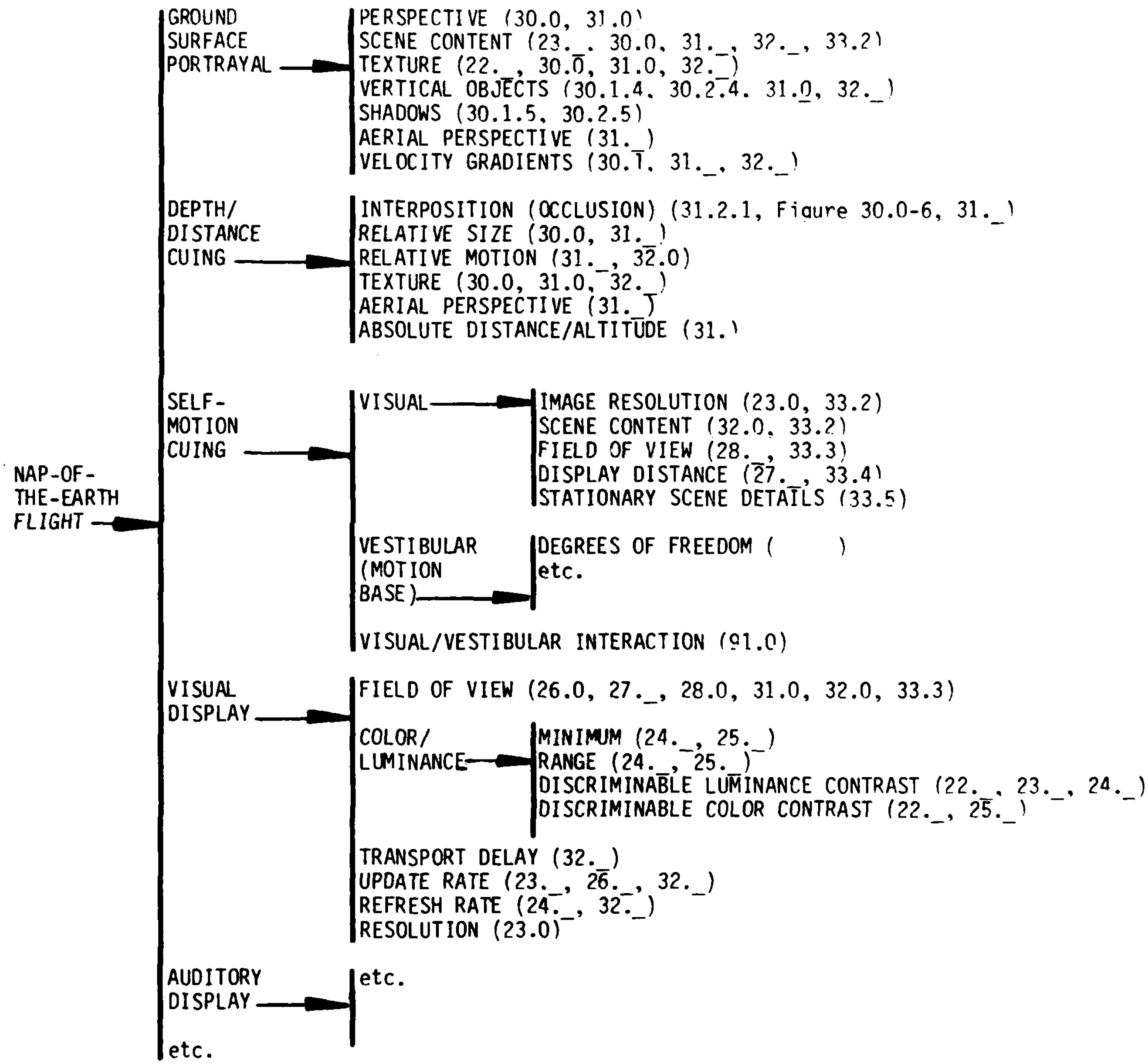


Figure 8.0-2 Data Base Sections Relevant to an ATD for Training Nap-of-Earth Flight

INTERACT WITH DISTANT AIRCRAFT →

- TARGET DETECTION (23._)
- TARGET IDENTIFICATION (23._)
- TARGET MOTION DETECTION (23._, 32._)
- TARGET MOTION INTERPRETATION (31._, 32._)
- DISTANCE ESTIMATION (31._)
- FIXED HIGH-RESOLUTION INSERT →
  - INSERT EDGE VISIBILITY (23._, 23._)
  - etc.
- EYE-SLAVED MOVABLE HIGH-RESOLUTION INSERT →
  - INSERT EDGE VISIBILITY (23._, 23._)
  - EYE MOVEMENT DYNAMICS (26.0)
  - etc.
- MULTIPLE HIGH-RESOLUTION INSERTS WITH VISIBLE EDGES →
  - TARGET ACQUISITION (23._)
  - etc.
- SELF-MOTION CUING →
  - etc.
- etc.

Figure 8.0-3 Data Base Sections Relevant to an ATD for Training Interaction with Distant Aircraft

SECTION 9.0 OVERVIEW OF EXPERIMENTAL METHODOLOGY

Psychophysical and statistical methodology will be summarized in this section. This summary is primarily intended to help individuals testing or otherwise evaluating ATDs or some feature of an ATD. Therefore it will describe approaches to such evaluations and the numerous potential pitfalls, and it will suggest potential sources of experienced guidance and assistance. Much of this information will also be helpful in understanding the research data summarized in the Data Base.

SECTION 10.0 TUTORIALS

This section will provide background technical material to insure that all Data Base users understand the implications of the data presented in the Data Base. Among the topics included will be a description of the physical parameters involved in perceptual research, and an explanation of how these are measured or specified. Among the more common of these parameters are light, color, sound and acceleration.

SECTION 17.0 ABBREVIATIONS, ACRONYMS, AND UNITS

This section defines and provides conversion factors for the physical units such as foot-Lamberts that are used in the Data Base or Users Guide. It also defines the abbreviations and acronyms used. For the present sample these are:

ATD - aircrew training device

CFF - critical flicker (or fusion) frequency

CGI - computer generated imagery

CIE - Commission Internationale de l'Eclairage (or International Commission on Illumination)

CIG - computer image generation

CRT- cathode ray tube

EMG- electromyograph (electrical activity of a muscle)

FOV - field of view

ICR - Integrated Cuing Requirements

MTF - modulation transfer function

SD - standard deviation (a measure of the variability in a set of data)

SL - sound level

SP - sound pressure

SPL - sound pressure level

TV - television

SECTION 18.0 GLOSSARY

The goals of this section are (1) to make the material in the Data Base and Users Guide more understandable and (2) to improve communication between the various groups concerned with ATDs, such as design engineers and perceptual psychologists. As a result, when completed it will provide definitions for a wide range of terms encompassing both perception and hardware. For the present paper, these are:

Accommodation (visual): Specifically, the dioptic adjustment of the eye to attain maximal sharpness of the retinal image for an object of regard. Focusing of the eye.

Active TV lines: The number of lines actually scanned on the photosensitive element of the camera or the CRT phosphor in a single frame, in distinction to the total number of scan periods per frame, including those needed for vertical retrace.

Adaptation (to light or dark): The adjustment occurring under changes in illumination, in which the sensitivity to light (or light threshold) is increased or reduced.

Aerial image displays: An image, especially a real image, formed by an optical system but percieved by alignment of the viewing eye with the path of light emerging from the optical system, instead of being focused first as an image on a receiving screen. Typical aerial image displays are the microscope, or a CRT viewed in a curved mirror.

Aliasing: In communications theory, the generation of spurious signals caused by sampling a signal at a rate lower than twice its frequency. In a CIG scene, sampling refers to the spatial frequencies involved in both the computation of the scene and its display. The result is spatial and/or temporal image defects. Manifestations of aliasing include edge stair-step, scintillation of small scene surfaces, breakup of long narrow surfaces, positional or angular motion of edges in discrete jumps or steps, more in regions where there is periodic structure, double imaging, and loss of dynamic image integrity due to field tracking induced by edge motion perpendicular to the scanning direction.

Anti-aliasing. Image processing techniques, usually involving low-pass filtering, that reduce spatial and/or temporal aliasing phenomena. To avoid significant reduction in image resolution, it is generally necessary to perform the anti-aliasing on an image with higher resolution than that of the one to be displayed.

Aspect ratio of a raster: The ratio of the frame width to the frame height.

Binocular: 1. Pertaining to both eyes; 2. The use of both eyes simultaneously in such a manner that each retinal image contributes to the final image.

Brightness: The subjective attribute of any light sensation giving rise to the perception of luminous intensity, including the whole scale of qualities of being bright, light, brilliant, dim, or dark. More popularly, brightness implies the higher intensities, and dimness implies the lower. At one time the term brightness was also used for the quantity luminance; this usage is no longer correct.

Candela: The unit of luminous intensity in the Commission Internationale de l'Eclairage or International Commission on Illumination (CIE) photometric system. It is 1/60 of the luminous intensity of 1 cm^2 of a blackbody radiator at the temperature of solidification of platinum. The term is intended by the CIE to be used in place of candle, international candle, and new candle.

Cathode ray tube (CRT): A tube in which the electrons emitted by a heated cathode are focused into a beam and directed toward a phosphor-coated surface that becomes luminescent at the point where the electron beam strikes it.

CFF (critical flicker frequency, critical fusion frequency, critical frequency for fusion): The rate of presentation of intermittent, alternate, or discontinuous photic stimuli that just gives rise to a fully uniform and continuous sensation obliterating the flicker.

Chromaticity: The attributes of chromatic color sensation, hue, and saturation collectively, as distinguished from intensity.

Chromaticity Coordinates: The ratios of each of the tristimulus values to the sum of the three. Symbols: x, y, and z.

Chromaticity diagram: A plane diagram formed by plotting two of the three chromaticity coordinates against one another, thus constituting a graphical representation of stimulus characteristics derived from color mixture data.

Collimate: 1. To render a bundle of rays parallel. 2. To adjust an optical instrument so that its mechanical and optical axes are coincident or parallel.

Color: 1. A sensory or perceptual component of visual experience, characterized by the attributes of hue, brightness, and saturation, and usually arising from, or in response to, stimulation of the retina by radiation of wavelengths between about 380 and 760 nm. Sensory components, such as white, gray, and black, which have neither hue nor saturation are properly, but are not always, included with colors. Variously synonymous with hue, tint, or shade. 2. A stimulus or a visual object which evokes a chromatic response.

Computer generated imagery (CGI): The images produced by means of computer image generation.

Computer image generation (CIG): The technology or techniques, for generating real-time pictures of a visual operating environment by digital processing of model data.

Contrast: 1. The difference in brightness between two areas. 2. Any one of several ways of mathematically expressing the difference in luminance of two areas.

Contrast sensitivity function: A curve depicting the contrast sensitivity of the eye as a function of spatial frequency.

Contrast threshold: The contrast associated with the minimum luminance difference between two areas which can be perceived as having different brightnesses.

Convergence angle (eye): The angle between the two visual axes.

Convergence angle (in color CRT's): The angle at which electron beams from separate color guns of a color CRT display come together at the phosphor.

Cornea: The transparent anterior (front) portion of the fibrous coat of the eye.

Crititical flicker frequency (see CFF)

Critical fusion frequency (see CFF)

CRT (see cathode ray tube)

Data base: A numerical representation of the visual scene that can be viewed in real-time with the CIG visual system. Data base conventions vary between reference to the total three-dimensional scene available over the gaming area and reference to just that scenery actually visible in the display FOV under specific viewing conditions.

Display: The physical device that forms an image for trainee viewing in an ATD. Two typical ATD displays are a CRT with optics to place the image near optical infinity, and a front or rear projection screen combined with a television projector.

Display field: The field of view, measured in terms of visual angle, as defined by the edges or limits of an image display.

Dynamic visual acuity: Visual acuity measured with a moving target.

Edge: In CIG, an edge is a straight or (rarely) curved line segment defined by two vertices of a polygon. Scene edges represent boundaries in the scene where either the shape, color, or brightness of scene detail changes. Consequently, natural fields, mountains, buildings, and so on are shaped and distinguished by edges of polygons.

Eye convergence angle (See Vergence)

Eyepoint: In a CIG ATD, the eyepoint is the simulated single point location of the observer's eye relative to a monocular scene presentation.

Field (in CRT displays): One of the equal parts into which a television frame is divided in an interlaced system of scanning. One vertical scan, containing many horizontal scanning lines, is generally termed a field.

Field of view (FOV): The horizontal and vertical subtended angles from the eyepoint.

Fixation point: The point in space to which one or both eyes are consciously directed. In normal vision its image is on the fovea.

Flicker: Perceptible temporal variation in luminance.

Fovea: A small pit in the center of the retina in which the density of photoreceptors is greatest and which controls perception of fine detail.

Foveal vision: Vision achieved by looking directly at objects so that the image falls on or near the fovea.

Frame (CRT): One complete scan of the image area by the electron beam. A frame may consist of several fields.

Frame rate (CRT): The number of frames produced per second; expressed in Hertz (Hz).

Gamut (color): The range of colors that can be obtained with a particular set of primaries or materials.

Glossiness (as a dimension of color): An attribute of the appearance of a surface dependent upon the type and the amount of reflection. Low glossiness is characteristic of rough diffusing surfaces and high glossiness of smooth surfaces that give a shiny or lustrous effect.

Gray: A color that is achromatic, or without hue, and which ranges from white to black.

Gray scale: A series of achromatic tones having varying proportions of white and black to give a full range of grays between white and black. These are usually regularly spaced with regard to reflectance or transmittance, and can be in either linear or log steps.

High order (CRT interlace system): An interlace system in which more than two fields are employed; e.g., 3:1, 4:1, interlace.

Horizontal resolution (CRT): The number of individual picture elements that can be distinguished in a horizontal scanning line within a distance equal to the picture height.

Hue: The attribute of color sensation ordinarily correlated with wavelength or combinations of wavelengths of the visual stimulus and distinguished from the attributes brightness and saturation. Comparable to "blue," "green," "yellow," etc.

Insert: In an ATD scene, the replacement of a portion of the scene by another scene, usually of higher resolution.

Interlace (CRT): A scanning process in which the distance from center to center of successively scanned lines is two or more times the nominal line width, and in which the intervening lines are scanned during subsequent fields.

Lateral alignment: The convergence angle or angle between the visual axes, necessary for the display user to fixate on corresponding points in the two images.

Line frequency (TV): The number of times per second that a fixed vertical line in the picture is crossed in one direction by the scanning spot. Scanning during vertical return intervals is counted.

Line number (TV): 1. The total number of line scan periods per TV frame. Not all of these periods are used to scan the image (in the camera) or the phosphor (in the CRT); a portion are used in vertical retrace. 2. The sequential numbering of the active TV lines on the sensor or phosphor surface.

Mesopic: Pertaining to vision at a luminance range in which both rods and cones function.

Metameric colors: Colors of different spectrophotometric composition which appear the same under given conditions. Appearance is often defined in terms of chromaticity.

Model board (ATD): A scale-model of a ground area or an aircraft, viewed with a servo-mounted televison camera and used to provide a visual scene for an observer in an ATD.

Modulation: Mathematically, the absolute value of the difference between two quantities, such as voltage or luminance at two times or at two locations, divided by their sum. Strictly speaking the variation in the value of the quantity should be sinusoidal, in which case the maximum and minimum values are used to calculate modulation. Modulation is one of several ways of expressing luminance contrast.

Modulation sensitivity: A statement of ability to distinguish differences in luminance, with these luminance differences expressed as modulation.

Modulation transfer function (MTF): The curve or the mathematical expression describing the curve generated by a series of modulation transfer factors taken over a range of frequencies, usually from a frequency of zero to the frequency at which the modulation transfer factor drops to zero.

Monocular: 1. Pertaining to or affecting one eye. 2. Pertaining to any optical instrument which is used with only one eye.

MTF (see modulation transfer function)

Munsell color system: A series of about one thousand standard color samples, each designated by a letter-number system. The series represents various combinations of hue, saturation, and brightness and includes variations of brightness of the achromatic colors which have neither hue nor saturation.

Occultation: The visual obstruction of scene lights and/or surfaces by other surfaces. Also referred to as interposition.

Octave: The interval between two frequencies having a ratio of 2:1.

Overlay: In an ATD scene, the adding of an image of a small object such as an aircraft over a larger generally homogeneous scene such as sky.

Overload: The condition in which the processing capacity of a CIG system is exceeded due to high scene complexity encountered under given viewing conditions.

Periphery (visual field): Noncentral portions of the field.

Phosphor persistence: The length of time required after the removal of excitation for the luminance of an excited phosphor to drop to 10 percent of its peak value.

Photopic: Pertaining to vision at a sufficiently high luminance that cone receptors are involved. An opposite meaning word is scotopic, for night seeing.

Pixel: Contraction of "picture element." The smallest element in a sampled image.

Purity (color): A measure of the degree of freedom of a color from achromatic content; or, the degree to which a color approaches the condition required for maximum saturation.

Radian: The angle subtended by an arc of circle equal in length to the radius of the circle. One radian is equal to 57.3 degrees.

Raster (CRT): A predetermined pattern of scanning lines that provides substantially uniform coverage of an area.

Raster luminance (CRT): The luminance of an extended area on the face of the CRT.

Real image: An optical image that can be received on a screen; one formed by the meeting of converging rays of light.

Recognition: In target acquisition, the assignment of an object (as seen on a display) to a class of objects: e.g., tank.

Recognition latency: The period of time elapsing between the first appearance of a target in display and a response by the observer indicating he has located and recognized it.

Refresh rate: The frequency with which the electron beam of a CRT display returns to a given phosphor spot. Nominally assumed equal to the frame rate.

Reliability: The coefficient of correlation obtained from two application of the same test. (Properly, the coefficient of reliability.)

Resolution (TV): A measure of ability to delineate picture detail. Resolution in cathode ray tubes is usually expressed as the number of scan lines in the vertical dimension of the raster (i.e., the direction perpendicular to the scan lines). A line of TV resolution is either the light or dark portion of a periodic target, as opposed to the designation of resolution as the number of line pairs (both the light and dark portions of a periodic target) used in optics. Two lines of TV resolution are required to equal one line pair of optical resolution.

Response latency: The lapse of time between the presentation of the stimulus and the occurence of the response.

Resting position (of accommodation): The refractive state of the eye when there is no stimulus to focus at any given distance. Traditionally spoken of as being zero diopter (accommodation to infinity), it is now more often placed nearer at about 0.5 to 2 diopters (2 to 0.5 meters); this is presumed to be the basis for night or empty field myopia.

Retina: The portion of the eye which contains the photoreceptors.

Retrace (in CRTs): Return of the beam on the cathode ray tube to its starting point after the completion of a line or a field; also that portion of the sweep waveform that returns the spot to its starting point.

Scan line (TV camera and CRT): A single continuous narrow strip that is determined by the process of scanning (the process of directing a beam of energy successively over the elements of a given region; e.g. a CRT tube).

Scene: The approximation of a real world visual environment the observer sees at any given moment while looking through the available aircraft windows on the simulator.

Scintillation: The apparent twinkling or quivering of a light source. It occurs when a very small object passes throught the center of a pixel and is represented by that pixel. Movement away from the center of the pixel into another pixel's domain causes the object to be underrepresented by either pixel until the object passes through the center of a second pixel. The net effect is that the object appears and disappears as it moves.

Scotopic: Pertaining to vision at relatively low luminance so that only rod receptors are involved.

Screen display: An image display in which the optical element closest to the eye is a diffusing surface or screen on which the image is formed. Also see aerial image displays.

Small field tritanopia: A normal reduction color discrimination for blue wavelengths for small color fields (nominally smaller that about 20 arc minutes), with the result that all colors can be matched by a mixture of two primaries, and purplish blues and greenish yellows are confused with neutral and with each other.

Snellen visual acuity: Measured by the ability to correctly read a standard set of letters of graduated size. Expressed as a comparison of the distance at which a given set of letters were correctly read to the distance at which the letters would be read by someone with clinically normal eyesight. A value of 20/80 indicates that an individual read at 20 feet the letters normally read at 80 feet.

Sound level (SL): A measure of the overall loudness of sounds based on an approximation of equal loudness of pure tones. It is a weighted measure, expressed in decibels, obtained by the use of a meter with specific weightings across the sound frequency spectrum.

Sound pressure level (SPL): The root-mean-square sound pressure expressed in decibels relative to a standard reference pressure (normally $2x10^{-5}$ N/m^2).

Spatial acuity: A general term referring to the visual ability to discriminate between targets on the basis of their relationships in space.

Spatial distribution: Allocation or apportionment of a quantity throughout a linear, real or spatial extent, such as cycles per millimeter or candelas per square meter. In distinction to temporal distribution, which is the apportionment of a quantity over a time period, such as cycles per second (Hz).

Spatial frequency: A measure of the number of cycles in a grating or target of alternating light and dark bars as a function of their linear extent. Normally measured in terms of cycles/millimeter or cycles/degree of visual angle. Used in distinction to temporal frequency (usually designated simply frequency) which is expressed in units such as cycles per second (Hz).

Staircasing: The appearance of a smooth diagonal as a staircase due to aliasing during image generation or because of a display raster.

Stereo acuity: The ability to percieve depth by the faculty of stereopsis, represented as a function of the threshold of stereopsis.

Stereopsis: 1. Binocular visual perception of three-dimensional space based on retinal lateral disparity; 2. Visual perception of depth or three-dimensional space.

Strobing: A pulsating luminant stimulus.

Surface: A typically opaque bounded area in a CIG scene forming a part of the runway, landmass, building, and the like.

Three-dimensional color space (for CRTs): A three-dimensional space defined by the amount of each of the three primary colors (red, blue, green) present on the display.

Threshold: The statistically determined point on the stimulus scale at which occurs a transition in a series of sensations or judgments.

Threshold contrast (see contrast threshold)

Transparency (as dimension of color): Attribute of appearance that permits perception of object or space through or beyond a surface.

Transport delay: The intervening time between the input and output in any system.

Triad (in color CRT's): A grouping of three colored phosphor dots (red-, blue- and green-emitting) on the face of a CRT.

Tri-bar test target: A target consisting of three equal-sized bars of defined length and width. Spacing between the bars is usually equal to bar width.

Trichromatism: Color vision in which mixtures of three independently adjustable primaries (i.e., red, green, and blue) are required to match all perceived hues.

TV line number: The number of scan periods per complete image scan (525 for U.S. commercial broadcast TV). The actual number of lines scanned on the camera image or CRT phosphor surface are less than the number of scan periods because of vertical retrace requirements. The lines actually scanned are referred to as the active lines.

Update rate: The frequency with which a data population is sampled by a system. It reflects the rate at which new values of changing state parameters are acquired by any system.

Vergence: 1. The angular relationship between the rays of light from a single object point. Usually expressed in diopters (1/apparent distance, in meters, to the source of the light rays). 2. In some sources, the angle between the visual axes of the two eyes. In this document, this angle is referred to as the "eye convergence angle," not as vergence.

Vernier acuity: Visual acuity based on the ability to detect the alignment or the nonalignment of two lines, as in the reading of a vernier scale.

Vertical resolution: 1. The number of active TV lines. 2. The number of distinct horizontal lines, alternately black and white, that can be seen in the CRT image of a television test pattern; it is primarily fixed by the number of horizontal lines used in scanning and by the Kell factor.

Visual acuity: 1. Ability to resolve or separate detail in a small high contrast target. 2. A unit equal to the reciprocal of the smallest resolvable target detail in arc minutes.

Visual angle: The angle subtended by the extremities of an object at the entrance pupil or other point of reference of the eye.

Visual field: The area or extent of physical space visible to an eye in a given position.

SECTION 19.0 INDEX

ICR USERS GUIDE - INDEX*

*NOTE: The ICR Users Guide Index has been updated for the existing paper. The reference page numbers for the subjects listed should be inserted as the new sections are completed.

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SECTION 30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE PAGE

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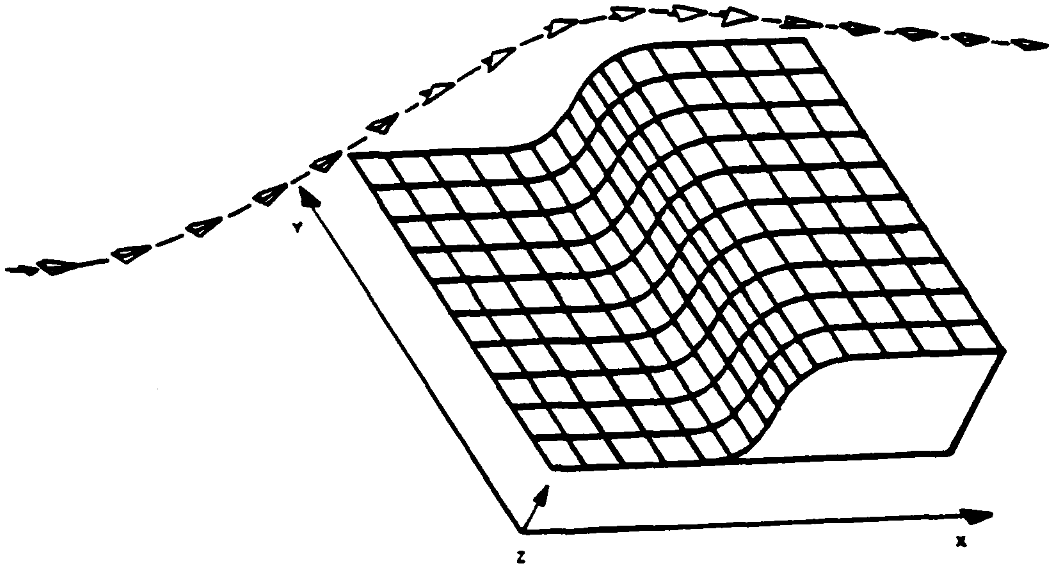
30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE



The pilot must be able to correctly ascertain the shape and slant of the terrain to reliably interact with the scene in an ATD visual display. Judgments about the local orientation of surfaces are based on several redundant sources of information in a normally viewed scene. Visual displays in ATDs can be difficult to interpret because many of these redundant sources of information are missing. For example, the computed scene in a CIG display may be misinterpreted when the scene is made up of simple polygons because these provide only limited surface orientation information and are subject to ambiguous interpretation.

Section 30.0 summarizes the relative effectiveness of different types of perceptual cues for surface orientation and shape judgements. Two points should be kept in mind.

(1) Even when the geometry of the scene is correct, observers can still see the scene wrong. For example, trapezoidal shapes are particularly difficult to see correctly (see Figure 30.2.2-3). Trapezoids are often seen as rectangles that are rotated in depth. The same illusion is reported for diamond shapes. Diamond are sometimes seen as squares turned and rotated in depth.

(2) An obviously artificial scene can lead to more accurate perceptions than a more realistic appearing scene. For example, adding texture to a scene can make it look more realistic. But if the texture is not perspectively correct, the texture will provide conflicting perceptual information that reduces the accuracy of orientation and shape judgments. The perceptual information available from a static display is qualitatively different than that of a dynamic display (See recommendation 1 in this section); therefore Section 30.0 is divided into two parts. Section 30.1 discusses the perception of dynamic scenes, and section 30.2 discusses the perception of static scenes.

30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE

Care must be taken to avoid conflicting perceptual cues. In addition to providing perceptual information about the true shape and orientation of surfaces in an ATD visual display, the designer must exercise professional engineering judgment to eliminate conflicting perceptual information.

Consequences of conflicting cues can be seen in much of the data collected by perceptual psychologists. For example, there are consistant errors in reports of judged slant. Observers tend to judge test images as being closer to a frontal plane than they really are. These errors can probably be attributed to conflicting cues permitted in the experimental apparatus. For example, assume the test image is a photograph of a slanted surface such as a tile floor, and the observer is asked to judge the slant of the surface. Unless the experimenter takes heroic pains to eliminate them, subtle cues such as film grain, lighting variations across the photograph, or even lack of motion parallax with minor head movements, will provide information that the observer is really viewing a flat display surface (the photograph) in the frontal plane. This will affect the judged slant of the tile floor.

Taking the idea of conflicting cues further, slant judgment experiments usually do not manipulate aerial perspective, relative brightness, or motion parallax cues, among others. Just because these cues were not manipulated does not mean that they did not provide information, only that they did not provide the correct information. Therefore, the results in the experiments often contain a constant bias towards the frontal plane. The estimates of the relative effectiveness of the different cues tested in these experiments are probably valid, however.

The ATD designer faces the same problem of conflicting cues. Any variable in the visual scene or the display hardware that is not correctly manipulated can provide conflicting perceptual information and reduce the perceptual fidelity of the ATD. Some examples of missing information that can produce cue conflicts are the lack of shadows and reflections (See Section 30.1.5 and 30.2.5), and the lack of aerial perspective (see Section 31.__). The effect of no aerial perspective can be seen in real life. When a person vacations in the desert, where the air is usually very clear, distances to objects tend to be severely underestimated. Some other sources of misleading information due to hardware are a visible CRT frame, visible raster lines, and dirt or scratches on the optics of the display.

The results of misperceiving the shape and orientation of a surface are not localized to that surface only. The misperception may cause the surrounding surfaces to be misperceived, as well as the self-motion, position, and attitude of the pilot.

The perception of the slant of a surface in a scene and the perception of distance in a scene are interrelated.. Quite often a cue to distance is a cue to slant, and vice-versa. Figures 30.0-1 through 30.0-13 illustrate some of the classical cues to relative distance and orientation (With the exception of Figure 30.0-5, all of the figures are adapted from Braustein, 1976, Ref. 6.) In general they have received little experimental investigation. Some of the literature testing their effectiveness has been integrated and summarized here, and much more data have been integrated into Section 31.0.

30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE

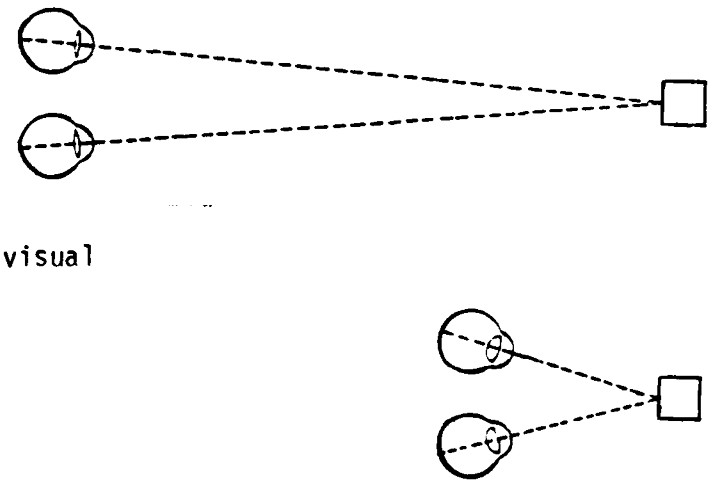


Figure 30.0-1
CONVERGENCE: The angle between the two visual axes.

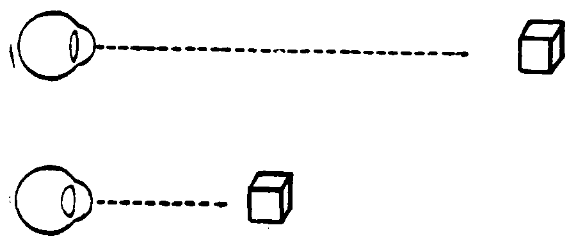


Figure 30.0-2
ACCOMMODATION: The change in the lens of the eye required to bring an image into focus.

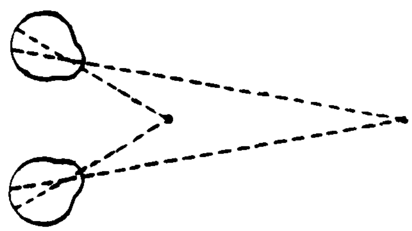


Figure 30.0-3
DISPARITY: A difference in the two images because of the different viewpoints of the two eyes.

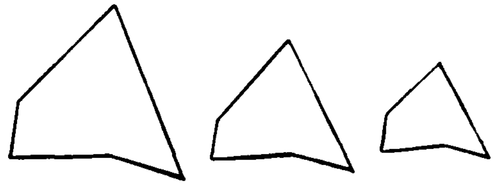


Figure 30.0-4
SIZES OF SIMILAR SURFACES: The smaller object is seen as farther away.

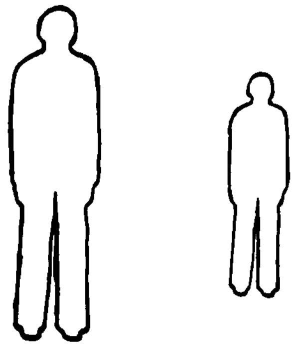


Figure 30.0-5
SIZES OF FAMILIAR OBJECTS: The smaller object is seen as farther away.

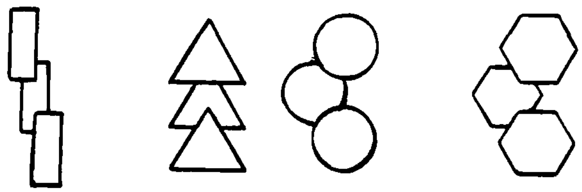


Figure 30.0-6
INTERPOSITION OF SURFACES: The middle object is seen as farther away than the others.
See Figure 30.2.2-2.

30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE

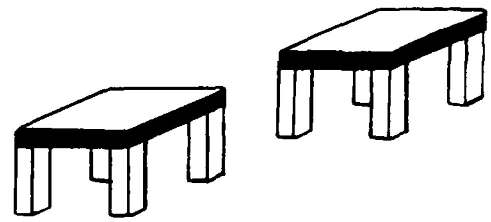


Figure 30.0-7
RELATIVE HEIGHT OF OBJECTS: The higher object is seen as farther away.

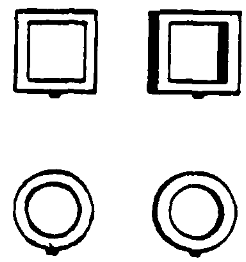


Figure 30.0-8
SHADOWS: The correct placement of shadows can enhance the perception of depth.
See Figure 30.1.5-1.

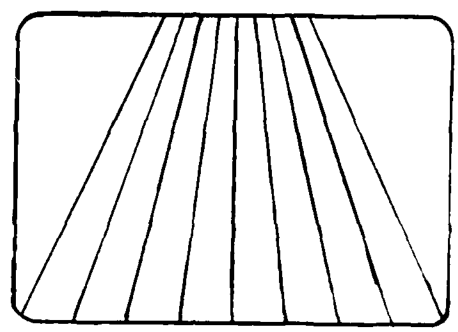


Figure 30.0-9
LINEAR PERSPECTIVE: Lines converge and objects get smaller as the distance increases.
See Figure 30.2.1-2.

Figure 30.0-10
TEXTURE GRADIENTS:
(a) Typical Irregular Texture
(b) Typical Regular Texture
The increasing density of a texture with distance is a cue to slant and distance. See Figure 30.2.1-1

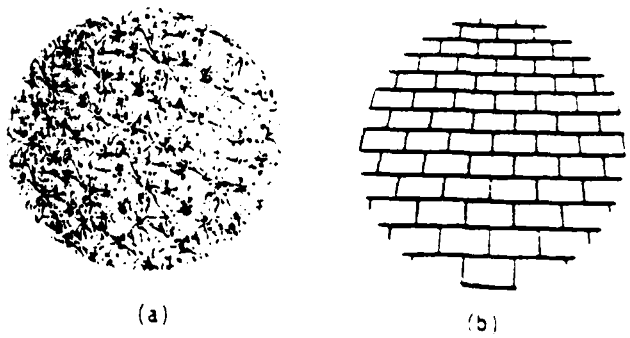


Figure 30.0-11
DYNAMIC PARALLAX (Motion Toward the Observer): Apparent change in the perspective shape of an object with motion.

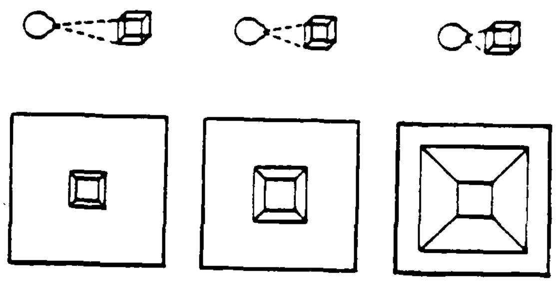


Figure 30.0-12
DYNAMIC PARALLAX (Motion From Left to Right): Apparent change in lateral displacement with motion.

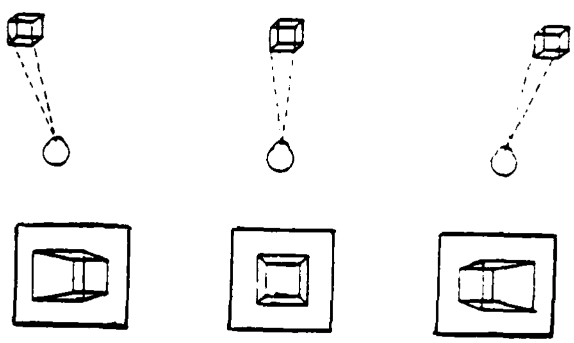
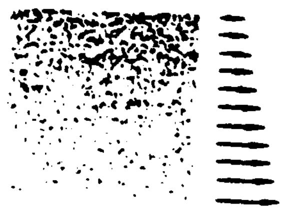


Figure 30.0-13
RELATIVE VELOCITY: Close objects move faster relative to the observer than distant objects. See Figure 30.1.1-2.



30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) Do not apply recommendations about a static scene to a dynamic scene, or vice versa, unless specifically recommended.	For example, there is little correlation between judgments and the accuracy of static slant judgments (Figure 30.1.2-1). While a static scene requires a regularly spaced texture (See Figure 30.2.1-1 for an example of regular and irregular texture), a dynamic scene does not (Figure 30.1.1-11).
2) The texture and objects in a scene must be perspectively correct.	The texture that is portrayed on a surface provides strong orientation information. If the texture is not perspectively correct, the texture will provide information to the observer that indicates that the surface is at some orientation other than the correct one.
CAUTION CUE CONFLICT: If the raster lines in a CGI display are visible, they will form a texture pattern that is not perspectively correct.	If the raster lines in a CGI display are visible, they will create a texture pattern on a surface in the screen. This texture pattern will give the observer slant information indicating that the displayed surface is vertical (in the plane of the screen).
3) Assume that intersecting lines and edges are often interpreted as intersecting at right angles at some (possibly incorrect) orientation in depth in an ambiguous scene.	This misinterpretation may not always occur. For example, if the surface is triangular in shape, all the angles could not possibly be right angles and hence may not be interpreted that way. If a misperception of the angle of intersection causes the orientation of the surface or object to be misjudged, the shape of the object may also be misjudged. This illusion is even more powerful in a dynamic scene than in a static scene. See section 30.1.2 for a discussion of the dynamic case, and section 30.2. for a discussion of the static case.

4) Use an intermediate size and spacing of texture elements to provide the best shape and slant information.

No adequate data exists to give quantitative guidance. The following qualitative limits are suggested.

The minimal density of the texture elements should be such that (1) the ground surface is sampled often enough to portray the maximum amount of irregularity required, and (2) the texture elements should be seen subjectively as related to each other. Even if these minimal conditions are not met, only two visible elements are required to give relative depth information in a dynamic scene (See Section 32.__ on motion parallax, and Section 31.__ on depth judgments and motion parallax).

The maximal density of the texture elements should be such that the individual texture elements do not overlap to the extent that they merge and form a uniform surface.

CAUTION

CUE CONFLICT: If the texture elements have a uniform size and regular spacing, severe temporal aliasing may result.

The illusion is similar to the stagecoach wagonwheel that appears to rotate backwards on television. See *section 32.__* for a discussion of the conditions of image velocity, update rate, and texture periodicity that lead to temporal aliasing.

5) Use vertically oriented objects to give altitude information, and to contribute to the perception of the orientation of surfaces.

Stevens (1979, Ref. 30) has demonstrated that observers can accurately adjust a line to be vertical to a plane defined by two other intersecting lines in a CRT display. This implies that observers may be able to use that information to make estimates of the orientation of a surface. Only anecdotal evidence exists. See section 30.1.4 and section 30.2.4 for a discussion.

6) Use shadows to give surface curvature information and orientation information.

The shadow cue for orientation judgments can dominate the perspective cue, and may be the only cue to the curvature of a surface. Section 30.2. 5 discusses shading and curved surfaces, and the relationship between shadows and perspective is discussed is section 30.1.5.

7) Assume that apparently overlapping faces affect the judged orientation of surfaces.

This may occur even if the faces were not intended to be seen as overlapping. Overlapping images are generally acknowledged as a cue to depth, but this has received little experimental verification. (Figure 30.2-2)

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) The stimuli used in these experiments are generally flat textured surfaces or a single line drawing.	The typical ATD display has a more complex scene, and these results must be applied with caution.
2) These experiments used a small field-of-view.	The effects of a larger field of view are generally unknown.
3) The types of motion are usually not the type generally encountered in an ATD display.	The types of motion used in the experiments summarized here are usually rotational or translational to the left or right.
4) The task that the observer was required to perform in the experiments to assess the accuracy of slant and shape judgments was not generally the task required in ATD.	Adjusting a board to match the judged slant of a picture may not give a good estimate of how well a trainee will perform in an ATD when the task is simulated flight.
5) The texture used in these experiments was typically composed of discrete elements rather than a continuous pattern.	The translation of the recommendations from discrete elements to a continuous pattern must be done using professional designer judgment. For example, the recommendation that discrete texture elements have an intermediate spacing would translate into the recommendation that the repetitiveness of a continuous pattern must have an intermediate frequency. In some cases, this may be a serious limitation. In general, the recommendations should give constructive guidance.

30.0 JUDGMENTS OF SURFACE ORIENTATION AND SHAPE

30.1 JUDGMENTS OF DYNAMIC SURFACE ORIENTATION AND SHAPE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) Do not apply recommendations about a static scene to a dynamic scene, or vice versa, unless specifically recommended.	For example, the accuracy of dynamic slant judgments is not related to the accuracy of static judgments (Figure 30.1.2-1). While a static scene requires a regulary spaced texture (Figure 30.2.1-1), a dynamic scene does not (Figure 30.1.1-1).
2) Assume that the shape of the texture elements does not affect slant judgments in a dynamic scene.	Figure 30.1.1-1 compares regular and irregular texture and shapes and indicates no difference in the accuracy of dynamic slant judgments. Figure 30.1.1-2 used a relative velocity cue for slant estimates in a texture having only a distribution density cue for slant estimates, and found that the relative velocity cue for slant was weighted about twice as heavily as the distribution density cue to depth.
CAUTION CUE CONFLICT: An illusory '*curvature*' may result in the scene when the size and shape of the texture elements are not perspectively correct.	See Figure 30.1.1-3.
CAUTION CUE CONFLICT: Assume that intersecting lines and edges are often interpreted as intersecting at right angles at some (possibly incorrect) orientation in depth in an ambiguous scene.	This misinterpretation may not always occur. For example, if the surface is triangular in shape, the angles could not possibly be right angles and may not be interpreted that way. If a misperception of the angle of intersection causes the orientation of the surface or object to be misjudged, the shape of the object may also be misjudged. This illusion is even more powerful in a dynamic scene than a static scene. See Section 30.1.2 for a discussion of the dynamic case, and Section 30.2.2 for a discussion of the static case.

30.1 JUDGEMENTS OF DYNAMIC SURFACE ORIENTATION AND SHAPE (CONT'D)

3) Use an intermediate size and spacing of texture elements to give shape and slant information.

(See Section 30.1.3) No adequate data exists to give quantitative guidance. The following qualitative limits are suggested.

The minimal density of the texture elements should be such that (1) the ground surface is sampled often enough to portray the maximum amount of irregularity required, and (2) the texture elements should be seen subjectively as related to each other. Even if these minimal conditions are not met, only two visible elements are required to give relative depth information in a dynamic scene (See Section 32. on motion parallax, and Section 31.__ on depth judgments and motion parallax).

The maximal density of the texture elements should be such that the individual texture elements do not overlap to the extent that they merge and form a uniform surface.

CAUTION

CUE CONFLICT: If the texture elements have a uniform size and regular spacing, severe temporal aliasing may result.

The illusion is similar to the stagecoach wagonwheel that appears to rotate backwards on television. See Section 32.__ for a discussion of the conditions of image velocity, update rate, and texture periodicity that lead to temporal aliasing.

4) Use vertically oriented objects to give altitude information, and to the perception of the orientation of the surface.

Only anecdotal evidence exists. See Section 30.1.4 for a discussion.

5) Assume that the shadow cue to orientation can dominate the perspective cue, and may be the only cue to curvature of a surface.

Section 30.2.5 discusses shading and curved surfaces, and the relationship between shadows and perspective is discussed in Section 30.1.5.

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.1 JUDGEMENTS OF DYNAMIC SURFACE ORIENTATION AND SHAPE (CONT'D)

6) <u>Specular reflections should be included in a display when possible.</u>	Specular reflections may be especially effective in a dynamic display, since the changing reflections change with the motion of the observer. No experimental evidence exists to give a quantitative estimate of the effectiveness of specular reflections. Since, in most cases, they are difficult to produce, this recommendation should be applied with caution.

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) <u>The stimuli used in these experiments are generally flat textured surfaces or a single line drawing.</u>	The typical ATD display has a more complex scene, and these results must be applied with caution.
2) <u>These experiments used a small field of view.</u>	The effects of a larger field of view are largely unknown.
3) <u>The types of motion are usually not the type generally encountered in an ATD display.</u>	The types of motion used in the experiments summarized here are generally rotational or translational to the left or right.
4) <u>The task that the observer was required to perform in the experiments to assess the accuracy of slant and shape judgments was not generally the task required in an ATD.</u>	Adjusting a board to match the judged slant of a picture may not give a good estimate of how well a trainee will perform in an ATD when the task is simulated flight.

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.1.1 JUDGEMENTS OF DYNAMIC ORIENTATION

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) The primary functions of texture in a dynamic scene is as a carrier of velocity gradient information. The specific form of the texture is unimportant.	Indirect evidence exists for this recommendation. (a) A random dot pattern gives poor slant information when static (Figure 30.1.1-2 and Figure 30.2.1-1), but gives good slant information in a dynamic scene (Figure 30.1.1-2). (b) In a static scene, a texture must have regularly spaced elements to be effective (Figure 30.2.1-1), but in a dynamic scene, the regularity of the pattern is unimportant (Figure 30.1.1-1).
2) The texture elements must be perspectively correct.	In cases where the texture elements were not kept perspectively correct, an illusory curvature in a flat plane is reported (Figure 30.1.1-3).

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) These experiments used a small field of view.	The effects of a larger field of view are largely unknown.
2) The types of motion are usually not the type generally encountered in an ATD display.	The types of motion used in the experiments summarized here are rotational or translational to the left or right.
3) The task that the observer was required to perform in the experiments was not generally the task required in an ATD.	Adjusting a board to match the judged slant of a picture may not give a good estimate of how well a trainee will perform in an ATD when the task is simulated flight.

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.1.1 JUDGEMENTS OF DYNAMIC ORIENTATION (CONT'D)

Figure 30.1.1-1 Judged Slant of a Dynamic Surface with Regular and Irregular Texture.

IMPLICATIONS
Irregular texture gives as much slant information in a dynamic scene as does regular texture.

REPRESENTATIVE STUDY
Gibson and Gibson (1957, Ref. 14)

METHOD
Stimuli: The four different stimuli are shown at the bottom of (a). The two texture patterns each contained 256 elements. There was only one shape in each of the form conditions.

Dynamic-The stimuli were rotated left and right from the frontal plane about a vertical axis to preselected maximum slant. They were visible for 20 seconds and were rotated at a speed of 0.5 revolutions per minute.

Static-The pattern was stationary for 20 seconds at the maximum slant.

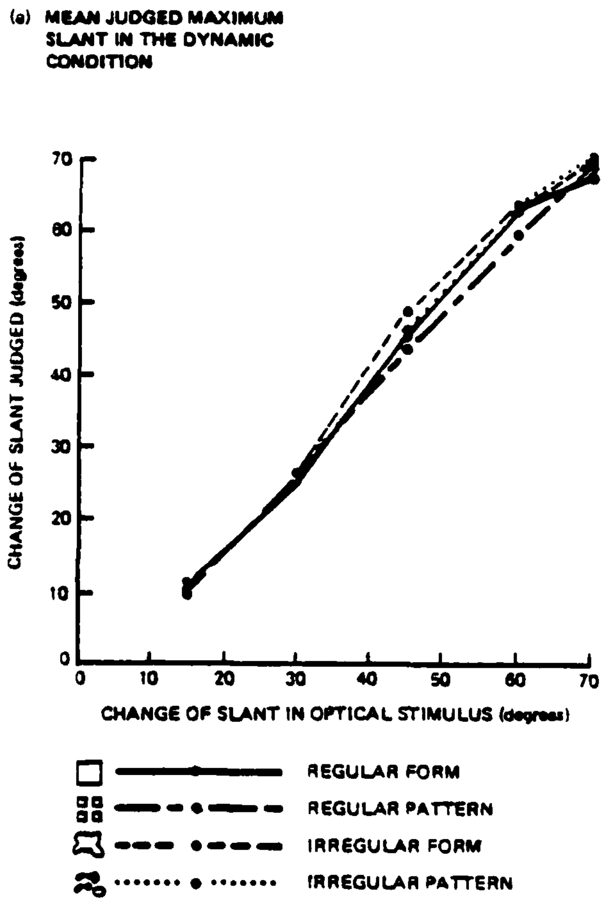
Response: Observers adjusted a protractor to indicate the judged maximum slant from horizontal.

RESULTS. See (a).
1) Dynamic - There was little difference between the different stimuli in accuracy of slant judgments.
2) Static - Judgments were less accurate than in the dynamic case.

LIMITATIONS
1) The type of oscillatory motion used is not the type of motion generally found in an ATD.
2) Adjustment of a protractor arm may give different results than the interactive manual control used in an ATD.

SUPPORTING LITERATURE
Flock (1964, Ref. 10) also found texture type to be unimportant.

CROSS-REFERENCE
See also Section 30.1.2 for a discussion of the perception of dynamic shape.



30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.1.1 JUDGEMENTS OF DYNAMIC ORIENTATION (CONT'D)

Figure 30.1.1-2 Judged Slant of a Textured Surface with Velocity Gradients and Distribution Density Gradients

IMPLICATIONS

1) Velocity gradients give more information than do distribution density gradients.
2) Distribution density gradients alone are a weak cue to slant.

REPRESENTATIVE STUDY

Braunstein (1968, Ref. 4)

METHOD

<u>Stimuli</u>: Random dot pattern were computer generated on film moving either to the left or right. The distribution density cue and the relative velocity cue could indicate the same or different degrees of slant. In (a) and (b) are represented static scenes with slants of 30 degrees and 90 degrees from horizontal, respectively. In (c) is a 30 degree distribution density cue and a 90 degree velocity cue. In (d) is a 90 degree density cue and a 30 degree velocity cue.

<u>Response</u>: Observers manually adjusted a board to indicate judged slant.

RESULTS. See (e).

A regression analysis showed that the relative velocity cue was weighted about twice as heavily as the density cue.

LIMITATIONS

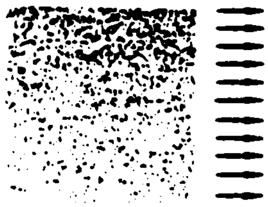
Adjustment of a board may give different results than the interactive manual control used in an ATD.

CROSS REFERENCE

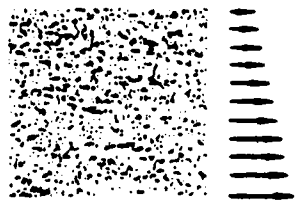
The distribution density cue for slant is weak by itself (See Figure 30.2.1-2). When the texture pattern is dynamic, the slant information is relatively independent of the characteristics of the texture. As an example, see Figure 30.1.1-1.

(a)

(b)



(c)



(d)

		RELATIVE VELOCITY CUE				
		STATIC	90°	70°	50°	30°
DISTRIBUTION DENSITY CUE	90°	90.3°	88.3°	78.4°	71.4°	69.3°
	70°	87.9°	90.2°	76.1°	71.2°	65.7°
	50°	88.2°	89.8°	74.5°	64.8°	61.3°
	30°	76.4°	87.6°	62.2°	58.2°	48.5°

(e) MEAN JUDGED SLANT (degrees from horizontal)

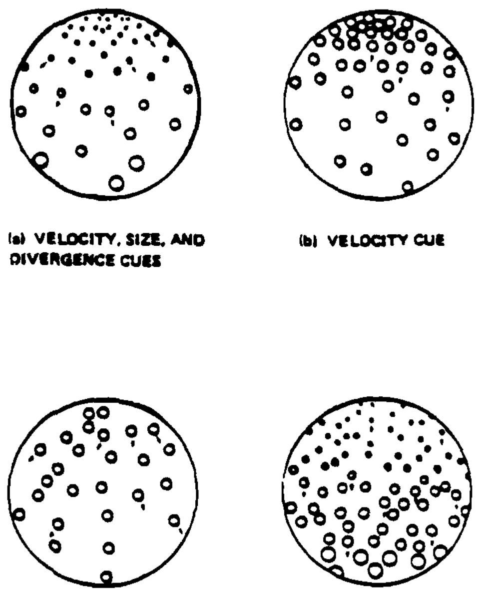
30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.1.1 JUDGEMENTS OF DYNAMIC ORIENTATION (CONT'D)

Figure 30.1.1-3 Judged Slant using Velocity Cues, Size Change Cues, and Divergence Cues.

IMPLICATION
1) Redundant information improves judged slant.
2) The size and shape of texture elements must be perspectively correct.

REPRESENTATIVE STUDY
Harrington and Harrington (1978, Ref. 17)
METHOD
Stimuli: A texture composed of small circles was computer generated and moved down the face of a CRT that was 4.5 degrees in diameter. Cues to slant were velocity (b), size change (d), and divergence of individual texture elements as they moved on the CRT (c). Cues were used individually, in all possible pairs, and with all three cues together (a).
Response: Observers manually adjusted a board to indicate judged slant.
RESULTS. See (e)
1) Redundant cues produce more accurate slant judgments.
2) Incorrect shape of the texture elements (apparently, the lack of perspective) caused the elements to not lie in the plane of the figure and caused the CRT screen to appear curved.
LIMITATIONS
1) Shape of the texture elements was not perspectively correct.
2) Use of a velocity cue was confounded with a distribution density cue.
3) Statistical analysis was not reported. Results should be considered as plausible, not proven.
4) Adjustment of a board to indicate the response may give different results than the interactive manual control task used in an ATD.
CROSS REFERENCE
1) Responses were collected in the periphery. See Section 28.__.
2) Importance of a perspectively correct shape is also true for static scenes. See Section 30.2.1.



(a) VELOCITY, SIZE, AND DIVERGENCE CUES

(b) VELOCITY CUE

(c) DIVERGENCE CUE

(d) SIZE CUE

AVAILABLE CUES TO SLANT	TRUE SLANT	VELOCITY DIVERGENCE SIZE (a) above	VELOCITY DIVERGENCE	VELOCITY SIZE	VELOCITY (b) above	DIVERGENCE SIZE	DIVERGENCE (c) above	SIZE (d) above
MEAN JUDGED SLANT	15°	60°	58°	68°	70°	73°	77°	79°

(e) JUDGED SLANT WITH VARIOUS DYNAMIC CUES

30.1.2 JUDGEMENTS OF DYNAMIC SHAPE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) In an ambiguous scene, intersecting lines and edges are often interpreted as intersecting at right angles, at some (possibly incorrect) orientation in depth.	This misinterpretation may not always occur. For example, if the surface is triangular in shape, the angles could not possibly be right angles and may not be interpreted that way. If a misperception of the angle of intersection causes the orientation of the surface or object to be misjudged, the shape of the object may also be misjudged. This illusion is even more powerful in a dynamic scene than as in a static scene. See Section 30.1.2 for a discussion of the static scene.
2) It is not necessary to make the shape regular in a dynamic scene.	No advantage has been found for regular patterns in a dynamic scene.

LIMITATIONS	SUPPORTING ANALYSIS
1) These experiments used in a single line drawing in a limited field of view.	How these results will generalize to the more complex scene that is typical of an ATD display in unknown.
2) The figures in these experiments were rotating.	How this type of motion will generalize to the type of motions more typically found in an ATD display is unknown.

CROSS REFERENCE:
Surfaces that apparently overlap may influence the judged shape and slant of a surface in an ATD. See figure 30.2.2-2 for a discussion of overlapping surfaces in a static scene.

SUPPORTING LITERATURE:
Langdon (1951, Ref. 23) reported results that imply that the perception of a circular shape is more accurate in a dynamic scene than in a static scene. Severe methodological problems make the usefulness of this study difficult to evaluate, but the results are plausible.

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

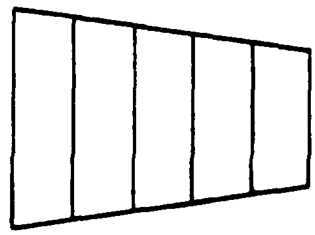
30.1.2 JUDGEMENTS OF DYNAMIC SHAPE (CONT'D)

Figure 30.1.2-1 Judged Slant of Dynamic Line Drawings With and Without Lines Intersecting at Right Angles.

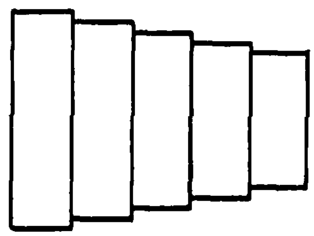
IMPLICATIONS
The proportion of correct dynamic slant judgments increases when the edges of a surface intersect at right angles.

REPRESENTATIVE STUDY
Braunstein and Stern (1979, Ref. 8)

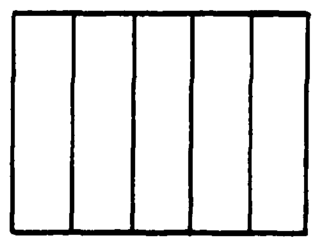
METHOD
Stimuli: A total of 18 line drawings were used. Three are shown in (a), (b), and (c). The drawings were computer generated on film. They were displayed rotating about a vertical axis. When the small end of the stimulus was actually nearer than the large end and the drawing was slanted away to the left, it was sometimes perceived as if the large end of the drawing was nearer and the drawing was slanted away to the right.
Response: Observers adjusted a board to indicate the instantaneous perceived direction of slant.



(a) PROPORTION OF ILLUSORY REVERSALS OF SLANT = 0.52



(b) PROPORTION OF ILLUSORY REVERSALS OF SLANT = 0.46



(c) PROPORTION OF ILLUSORY REVERSAL OF SLANT = 0.10

RESULTS
The proportion of correct judgments of which end was nearer is shown in (a), (b), and (c) for these three stimuli. An overall analysis of the 18 drawings showed that the illusory reversals of perceived slant were caused by the non-rectangular line intersections.

LIMITATIONS
1) Rotation is not a normal mode of motion in an ATD.

SUPPORTING LITERATURE
Langdon (1951 Ref. 23) investigated the judged shape of rotating circles. Results suggested that the shape of a circle was more accurately seen when the circle was rotating than when it was static.

CROSS REFERENCE
See also Section 30.1.1 for the judged slant of regular and irregular drawings and textures.

30.1.2 JUDGEMENTS OF DYNAMIC SHAPE (CONT'D)

Figure 30.1.2-2 Judged Slant of a Dynamic Surface with Regular and Irregular Shape.

IMPLICATIONS

Irregular shapes give as much slant information in a dynamic scene as do regular shapes.

REPRESENTATIVE STUDY

Gibson and Gibson (1957, Ref. 14)

METHOD

Stimuli: The four different stimuli are shown at the bottom of (a). The two shape stimuli consisted of a single regular form and a single irregular form.

Dynamic - The stimuli were rotated left and right from the frontal plane about a vertical axis to some preselected maximum slant. They were visible for 20 seconds and were rotated at a speed of 0.5 revolutions per minute.

Static - The pattern was stationary for 20 seconds at the maximum slant.

Response: Observers adjusted a protractor to indicate the judged maximum slant.

RESULTS. See (a).

1) Dynamic-There was little difference between the different stimuli in accuracy of slant judgments.

2) Static-Judgments were less accurate than in the dynamic case.

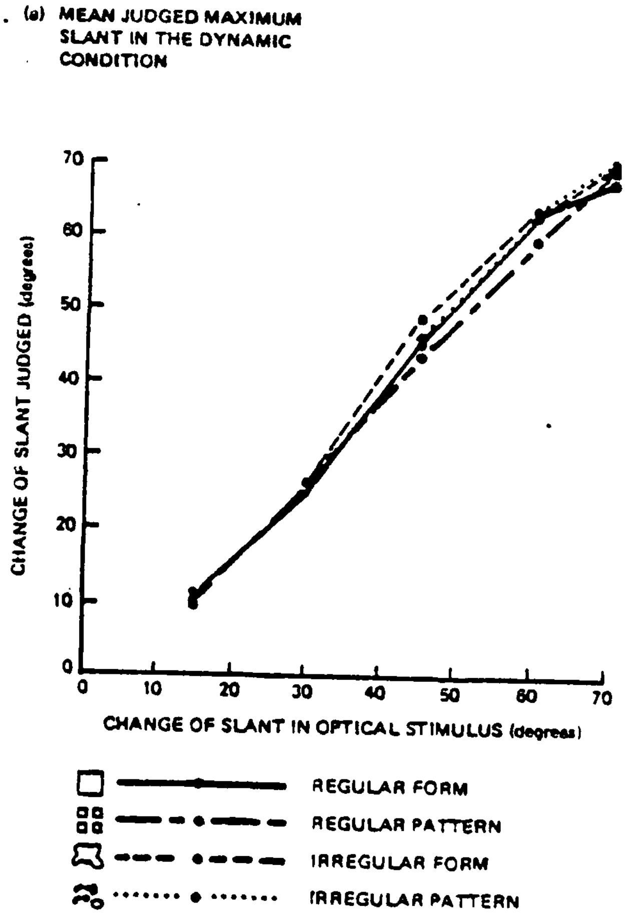
LIMITATIONS

1) The type of oscillatory motion used is not the type of motion generally found in an ATD.

2) Adjustment of a protractor arm may give different results than the interactive manual control used in an ATD.

CROSS REFERENCE

See also Section 30.2.2 for a discussion of the perception of static shape.



30.1.3 TEXTURE ELEMENT SIZE AND DENSITY

RECOMMENDATIONS

1) <u>Use an intermediate size and spacing of texture elements to give the best shape and slant information.</u>

SUPPORTING LITERATURE

No adequate data exist to give quantitative guidance. The following qualitative limits are suggested.

The <u>minimal density</u> of the texture elements should be such that (1) the ground surface is sampled often enough to portray the maximum amount of irregularity required, and (2) the texture elements should be seen subjectively as related to each other. Even if these minimal conditions are not met, only two visible elements are required to give relative depth information in a dynamic scene (see Section 32. on motion parallax).

The <u>maximal density</u> of the texture elements should be such that the individual texture elements do not overlap to the extent that they merge and form a uniform surface.

CAUTION

<u>CUE CONFLICT: If the texture elements have a uniform size and regular spacing, severe temporal aliasing may result.</u>

The illusion is similar to the stagecoach wagonwheel that appears to rotate backwards on television. See Section 32.__ for a discussion of the conditions of image velocity, update rate, and texture periodicity that lead to temporal aliasing.

LIMITATIONS OF THE RECOMMENDATIONS

1) <u>No experimental evidence exists to support this recommendation.</u>

SUPPORTING ANALYSIS

This recommendation should be considered plausible, but not proven.

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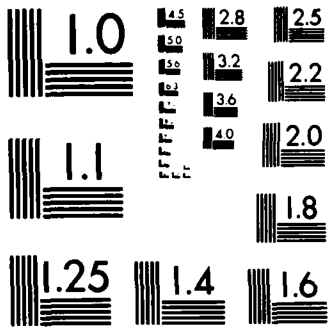


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.1.4 VERTICAL OBJECTS IN A DYNAMIC SCENE

RECOMMENDATION	SUPPORTING ANALYSIS
1) Use vertical objects in a dynamic scene to provide information about ground surface orientation and altitude.	Anecdotal evidence gives support to the suggestion that vertically organized objects improve altitude control in an aircraft simulator (Rife, 1980, Ref. 29). Interviews with pilots have indicated that flying over surfaces with no vertical objects (for example, snow fields or calm water) makes visual control of altitude difficult. To the extent that the visual control of altitude depends on accurate judgment of the orientation of the ground surface, vertical objects improve orientation judgments.

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) No experimental evidence exists to support this recommendation.	This recommendation should be considered plausible, but not proven.

CROSS REFERENCE:

See also the following sections.

30.2.4 - Vertical objects in a static scene
31.___ - Motion parallax.
32.___ - Distance judgments.

30.1.5 SHADOWS AND REFLECTIONS IN A DYNAMIC SCENE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) Specular reflections should be included in a display when possible.	Specular reflections may be especially effective in a dynamic display, since the changing reflections change with the motion of the observer. No experimental evidence exists to give a quantitative estimate of the effectiveness of specular reflections. Since, in most cases, they are difficult to produce, this recommendation should be applied with caution.
2) Shadows and smooth shading should be integrated into the display.	In a static scene, shadows may provide the only cue to the curvature of a surface. Lack of shadows and smooth shading can result in a curved surface being judged as flat. (Figure 30.2.5-1) Figure 30.1.5-1 implies that shadows are especially effective in a dynamic scene for slant judgments.

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) There is little experimental evidence to assess the need for specular reflections in a dynamic scene.	Therefore the recommendation should be considered plausible, not proven.
2) The type of motion used in Figure 30.1.5-1 to assess the importance of shadows in a dynamic scene was rotational.	The importance of shadows when the motion is more nearly like that found in an ATD display has not been assessed.

CROSS REFERENCES:

See Section 30.2.5 for a discussion of shadows in a static scene.

30.1.5 SHADOWS AND REFLECTIONS IN A DYNAMIC SCENE (CONT'D)

Figure 30.1.5-1 Judged Slant of Plane Figures with Shadows.

IMPLICATION
Shadows provide dynamic slant information.

REPRESENTATIVE STUDY
Cross and Cross (1969, Ref. 9)

METHOD

Stimuli: Both rectilinear and circular line drawings were used. See (a). The figures could have either reinforcing or conflicting perspective and shadow cues for slant estimates. The figures were rotated about a vertical axis.
Response: Observers pressed a button to indicate the judged direction of slant.

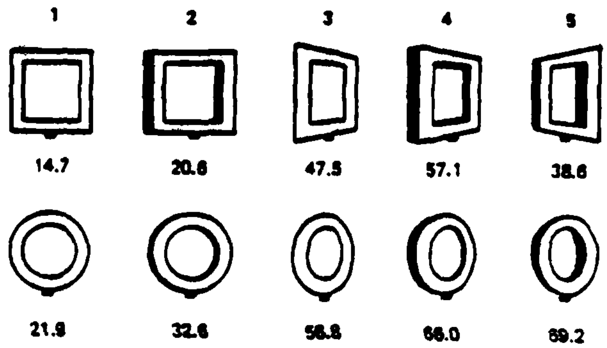
RESULTS. See (a)

1) Shadows than were drawn incorrectly produced illusory reversals of judged slant.
2) When shadows and linear perspective were presenting conflicting information, the shadow information was dominant.

LIMITATIONS
The type of motion used in this experiment (rotary) is not the type of motion typically found in an ATD.

CROSS REFERENCE
See also Section 30.2.5 for a discussion of the effects of shadows on the perception of a static curved surface.

(a) LINE DRAWINGS USED IN THE EXPERIMENT. NUMBERS BELOW THE DRAWINGS INDICATE THE PERCENTAGE OF ILLUSORY REVERSALS OF DYNAMIC SLANT.



1 – NO CONFOUNDING CUES
2 – SHADOW CUES
3 – LINEAR PERSPECTIVE
4 – SHADOWS AND PERSPECTIVE INDICATING THE SAME DIRECTION OF SLANT
5 – SHADOWS AND PERSPECTIVE INDICATING OPPOSITE DIRECTION OF SLANT

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.2 JUDGEMENTS OF STATIC SURFACE ORIENTATION AND SHAPE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) Do not apply recommendations about a static scene to a dynamic scene, or vice versa, unless specifically recommended.	For example, the accuracy of dynamic slant judgments is not correlated to the accuracy of static slant judgments. (Figure 30.1.2-1) While a static scene requires a regularly spaced texture (Figure 30.2.1-1), a dynamic scene does not (Figure 30.1.1-2).
2) The optimal texture for a static scene consists of square texture elements arranged in regular rows and columns.	An example of this would be a checkerboard texture pattern. This recommendation is derived from the two following recommendations.
2.1) Use orderly rows of surfaces or objects that converge into the distance to portray static surfaces.	This can be accomplished by using regular texture (Figure 30.2.1-1), or regularly spaced vertical objects. (The need for vertical objects is discussed in Section 30.2.4.) The importance of lines that converge in distance, and rows of objects or surfaces that converge in the distance is discussed in Figure 30.2.1-2.
2.2) Assume that perspectively correct size and shape of surfaces or objects tend to contribute strong surface slant information, especially if the objects are rectangular.	The size and shape of texture elements are more important than their distribution density (Figure 30.2.1.3), and lines and edges than intersect at right angles tend to be perceived correctly (Figure 30.2.2-1).
3) Assume that intersecting lines and edges are often interpreted as insecting at right angles, at some (possibly incorrect) orientation in depth in an ambiguous scene.	This misinterpretation may not always occur. For example, if the surface is triangular in shape, the angles could not possibly be right angles and may not be interpreted that way. If a misperception of the angle of intersection causes the orientation of the surface or object to be misjudged, the shape of the object may also be misjudged. (See figure 30.2.2-1).

30.2 JUDGEMENTS OF STATIC SURFACE ORIENTATION AND SHAPE (CONT'D)

4) Assume that apparently overlapping faces affect the judged orientation of surfaces.

This may occur even if the faces were not intended to be seen as overlapping images are generally acknowledged as a cue to depth, but this has received little experimental verification. (Figure 30.2.2-2)

5) Assume that misperceptions of the orientation of a surface may cause a misperception of the shape of that surface, and vice versa.

Recommendations 3 and 4 from above may cause the shape or orientation of a surface to be misperceived. (Figure 30.2.2-3)

6) Use an intermediate size and spacing of texture elements to give shape and slant information.

(See Section 30.1.3). No adequate data exist to give quantitative guidance. The following qualitative limits are suggested.

The minimal density of the texture elements should be such that (1) the ground surface is sampled often enough to portray the maximum amount of irregularity required, and (2) the texture elements should be subjectively seen as related to each other.

The maximal density should be such that the individual texture elements do not overlap to the extent that they become a uniform surface.

7) Use vertically oriented objects to give altitude information, and to contribute to the perception of of orientation of the surface.

Only anecdotal evidence exists for this recommendation. Therefore, it should be considered plausible, but not proven. Refer to Section 30.2.4 for a discussion.

8) Use the correct shading and shadows to give information about surfaces, especially curved surfaces.

Shape information from shadows have been shown to dominate perspective information when the two types of information are in conflict in a dynamic scene. See Section 30.1.5 for a discussion. Shadows may be the only source of information about the curvature of a surface in a static scene.

30.2 JUDGEMENTS OF STATIC SURFACE ORIENTATION AND SHAPE (CONT'D)

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) The experimental results should apply to static scenes only.	The information in Section 30.2 does not, in general, apply to a dynamic scene.
2) The stimuli used in these experiments are generally flat textured surfaces, or an isolated line drawing.	The typical ATD display is a more complex scene, and these results should be applied with caution.
3) The experiments generally used a small field of view.	The effects of a larger field of view are unknown.
4) The task that the observer was required to perform in the experiments to assess the accuracy of shape and shape judgments was not generally the task required in an ATD.	Adjusting a board to match the judged slant of a picture may not give a good estimate of how well a trainee will perform in an ATD when the task is simulated flight.

30.0 JUDGMENTS OF JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.2.1 JUDGEMENTS OF STATIC ORIENTATION

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) <u>Texture patterns should have uniform size and spacing.</u>	A regularly spaced texture gives better slant information. (See Figure 30.2.1-1). In a dynamic scene, the regularity of texture elements is not as important as in a static scene. See Section 30.1.1.
CAUTION	
<u>CUE CONFLICT:</u> Regular texture patterns can cause severe temporal aliasing. See section 32.___.	The illusion is similar to the stagecoach wagonwheel that appears to rotate backwards on television. See Section 32.__ for a discussion of the conditions of image velocity, update rate,and texture periodicity that lead to temporal aliasing.
2) <u>Texture patterns should not be only one-dimensional.</u>	(See Figure 30.2.1-1) If the texture is only one-dimensional, on some headings the trainee will not have any convergence cues for slant estimates.
3) <u>The size and shape of texture elements must be perspectively correct.</u>	If the size and shape of the texture elements are not kept perspectively correct, a distortion of the perceptual shape of the scene may result. (Figure 30.2.1-3)
LIMITATIONS OF THE RECOMMENDATIONS	
1) <u>These experiments generally use a single, flat surface and a small field of view.</u>	How these data apply to a display where each surface is only part of a larger scene has yet to be analyzed.
2) <u>These results apply only to a static scene.</u>	See Section 30.1.1 for a discussion of the judged slant of surfaces in a dynamic scene.

30.2.1 JUDGEMENTS OF STATIC ORIENTATION (CONT'D)

Figure 30.2.1-1 Judged Slant of Regular and Irregular Texture.

IMPLICATION
Regular texture gives more slant information than irregular texture in a static scene.

REPRESENTATIVE STUDY
Newman, Whinham, and MacRae (1973, Ref 25)

METHOD
Stimuli: Six photographs of natural textures taken at three angles, as shown in (c). Examples of the two types of textures used are shown in (a) and (b).
Response: Observers manually adjusted the arm of a protractor to indicate judged slant.

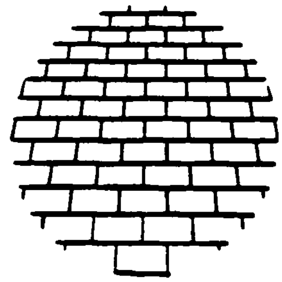
RESULTS. See (c).
1) Regular textures gave better slant judgments than irregular textures.
2) Slant judgments were more accurate with decreasing slant.

LIMITATIONS
1) Stimuli were static. Results may not generalize to a dynamic scene.
2) Adjustment of a protractor arm may give different results than the interactive manual control used in an ATD.

SUPPORTING LITERATURE
Flock and Moscatelli (1964, Ref. 11) systematically varied the variability of artificial texture. Braunstein and Payne (1969, Ref. 7), Gibson (1950, Ref. 13), Kraft and Winnick (1967, Ref. 22)

CROSS REFERENCE
Regular texture also give better size and distance judgments. See Section 31.0, Gibson (1950, Ref. 13), and Wohlwill (1962, Ref. 31).

(a) IRREGULAR TEXTURE FROM GIBSON (1950, Ref. 13)



(b) REGULAR TEXTURE FROM GIBSON (1950, Ref. 13)

TEXTURE TYPE	ACTUAL TEXTURE	ACTUAL SLANT		
		30°	25°	20°
REGULAR	PAVING STONES BRICKS TILES	38°	32°	25°
IRREGULAR	PEBBLES CONCRETE GRASS	42°	38°	28°

(c) JUDGED SLANT WITH DIFFERENT TEXTURES

30.2.1 JUDGEMENTS OF STATIC ORIENTATION (CONT'D)

Figure 30.2.1-2 Judged Slant of Parallel Lines.

IMPLICATIONS
Parallel lines along the line of sight give more slant information than parallel lines across the line of sight.

REPRESENTATIVE STUDY
Gillam (1968, Ref. 15)

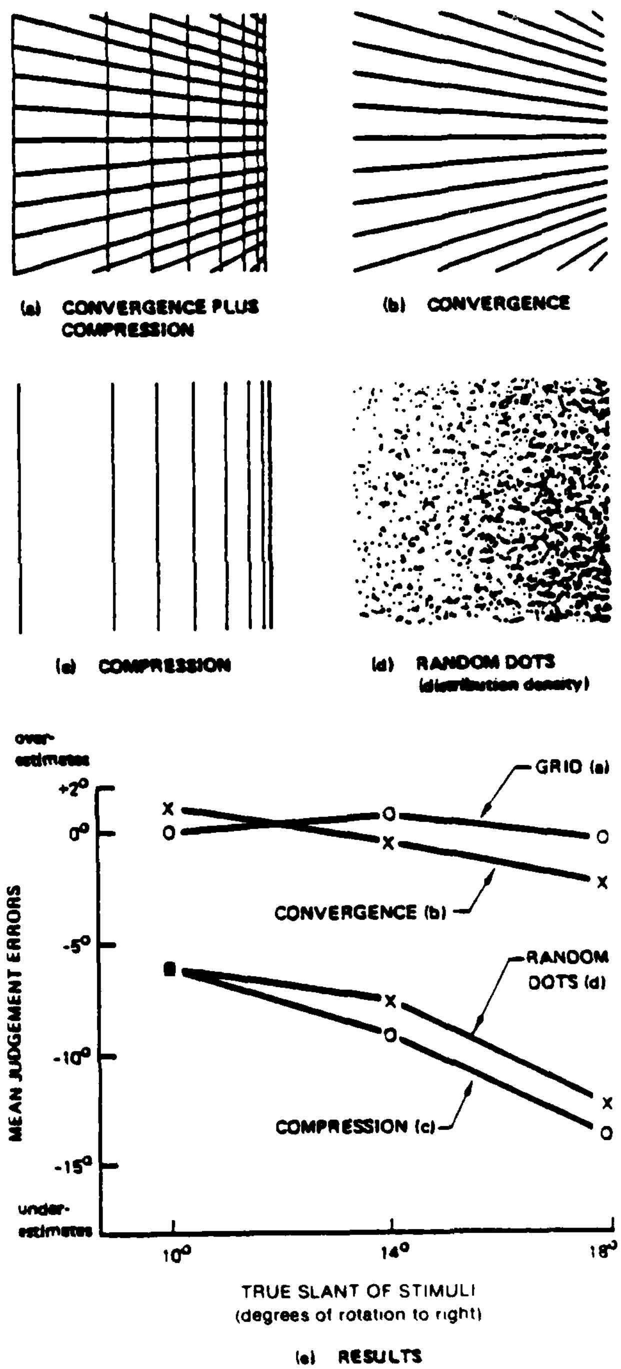
METHOD
Observers manually adjusted a board to match the judged slant of one of the four stimuli shown slanted either 10 degrees, 14 degrees, or 18 degrees.

RESULTS. See (e)
1) Stimuli (a) and (b) gave more slant information than (c) and (d).
2) Stimulus (a) did not differ from (b), and (c) did not differ from (d).

LIMITATIONS
1) Stimuli were static. Results may not generalize to a dynamic scene.
2) Adjustment of a protractor arm may give different results than the task used in an ATD.
3) Stimuli were rotated about a vertical axis. This is probably not a serious limitation.

SUPPORTING LITERATURE
Attneave and Olson (1966, Ref. 1), and Rosinski and Levine (1976, Ref. 30).

CROSS REFERENCE
Stimuli (a) and (b) also give more distance information. See Section 31.0, and Levine and Rosinski (1976, Ref. 24).



30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.2.1 JUDGEMENTS OF STATIC ORIENTATION (CONT'D)

Figure 30.2.1-3 Judged Slant of Texture with Elements Changing in (1) Size and Shape or (2) Distribution Density.

IMPLICATION
The size and shape of texture elements give more information than does the relative density of the texture.

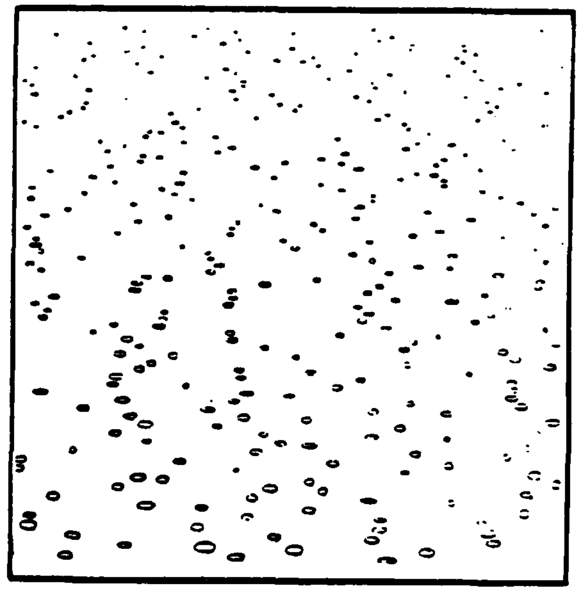
REPRESENTATIVE STUDY
Phillips (1970, Ref. 27)

METHOD
Procedure: Observers looked at pairs of photographs and indicated which was closer to horizontal.
Stimuli: Each photograph was similar to (a). In photograph (a), the size and shape of the texture elements indicate a 20 degree slope, and the relative distribution density indicates a 45 degree slant.

RESULTS. See (b).
When the two types of cues were in conflict, judged slope almost completely folowed size and shape cue. Relative distribution density had little influence on judged slant.

LIMITATIONS
1) Stimuli were static. Results may not generalize to a dynamic scene.
2) Slant judgments were relative and do not indicate the absolute accuracy of slant judgments.

CROSS REFERENCE
Judged shape and judged slant are mutually interdependent. See Sections 30.1.2 and 30.2.2.



SIZE AND SHAPE CUE = 20 DEGREES FROM FROM HORIZONTAL
DISTRIBUTION DENSITY CUE = 45 DEGREES FROM HORIZONTAL

(a) EXAMPLE OF TEXTURE

PERCENTAGE OF TIMES SIZE AND SHAPE CUE DOMINATED DISTRIBUTION DENSITY CUE	PERCENTAGE OF TIMES DISTRIBUTION DENSITY CUE DOMINATED SIZE AND SHAPE CUE
96%	4%

(b) RESULTS WHEN SIZE AND SHAPE CUE = 20 DEGREES AND DISTRIBUTION DENSITY CUE = 45 DEGREES (OR VICE-VERSA)

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.2.2 JUDGEMENTS OF STATIC SHAPE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) Assume that when edges intersect they are judged as intersecting at right angles, even if they must be mentally rotated out of their intended orientation to be seen that way.	This misinterpretation may not always occur. For example, if the surface is triangular in shape, the angles could not possibly be right angles and may not be interpreted that way. If a misperception of the angle of intersection causes the orientation of the surface or object to be misjudged, the shape of the object may also be misjudged. This illusion is even more powerful in a dynamic scene than in a static scene. See Section 30.2.2 for a discussion of the static case.
2) Assume that apparent face overlap affects judged orientation.	This may occur even if the faces were not intended to be seen as overlapping. (Figure 30.2.2-2)
3) Assume that misperceptions of the orientation of a surface can cause misperception of the shape of that surface, and vice versa.	The perception of slant and the perception of shape are interdependent. *(See Figure 30.2.2-3)*

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) These studies generally use a single line drawing in an impoverished scene.	How these data apply to a scene where each surface is only part of a complex scene has yet to be analyzed.
2) These results apply only to a static scene.	See Section 30.1.2 for a discussion of shape judgments in a dynamic scene.

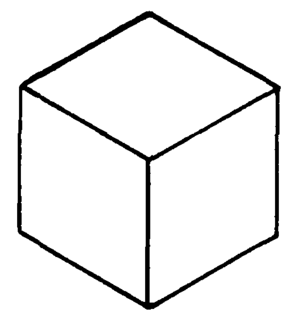
30.2.2 JUDGEMENTS OF STATIC SHAPE (CONT'D)

Figure 30.2.2-1 Judged Angle of Intersection of Corners in a Line Drawing.

IMPLICATION
Lines tend to be seen as intersecting at right angles.

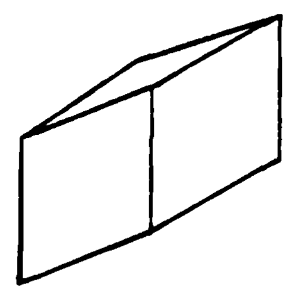
REPRESENTATIVE STUDY
Perkins (1972, Ref. 26)

METHOD
Stimuli: The stimuli were line drawings that could be a projection either of a figure with right angles (a) or of a figure that could not have right angles (b).
Procedure: Three different procedures were used. The observers (1) saw the drawings one at a time, (2) saw the drawings next to standard drawings for comparison, or (3) saw the drawings in pairs, one of which was rectangular. In each case the observer had to make a rectangularity judgment.



(a) LINE DRAWING THAT COULD REPRESENT RECTANGULAR CORNERS

RESULTS. See (c).
There was a strong tendency to judge stimuli as rectangular if and only if they could represent a rectangular figure.



(b) LINE DRAWING THAT COULD NOT REPRESENT RECTANGULR CORNERS

LIMITATIONS
1) The stimuli were static.
2) The stimuli were drawings of boxes. This is probably not a serious limitation.

SUPPORTING LITERATURE
Stevens (1978, Ref. 31)

CROSS REFERENCE
This tendency to see lines as intersecting at right angles is possibly stronger in a dynamic scene. See Section 30.1.2, and Braunstein (1971, Ref. 5)

TEST PROCEDURE	STIMULI THAT COULD BE RECTANGULAR	STIMULI THAT COULD NOT BE RECTANGULAR
1	92%	19%
2	88%	14%
3	94%	7%

(c) PERCENTAGE OF RECTANGULAR JUDGEMENTS

30.2.2 JUDGEMENTS OF STATIC SHAPE (CONT'D)

Figure 30.2.2-2 Judged Slant of a Line Drawing with Apparently Overlapping Surface.

IMPLICATION
Surfaces that apparently overlap may cause a misperception of the true slant of the surface. This may occur even though the surfaces were not intended to overlap.

REPRESENTATIVE STUDY
Braunstein and Stern (1979, Ref. 8)

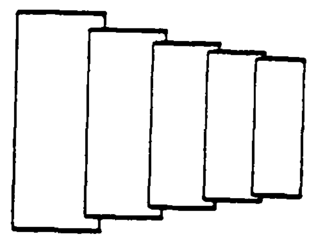
METHOD
Stimuli: Eighteen different drawings were used in this experiment. An example of overlapping surfaces is shown in (a), and non-overlapping surfaces shown in (b).
Procedure: Observer adjusted a board to indicate judged slant.

RESULTS. See (a) and (b).
Apparently overlapping surfaces interfered with the perception of slant.

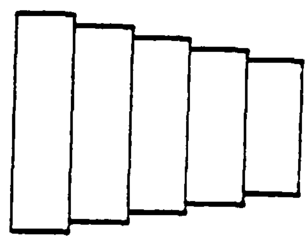
LIMITATIONS
1) The stimuli were static.
2) The stimuli were slanted about a vertical axis. This is probably not a severe limitation.

SUPPORTING LITERATURE
Although overlapping surfaces and interposed surfaces are widely accepted cues depth, they have received little experimental study under normal viewing conditions. A general discussion of these cues in contained in Braunstein (1976, Ref. 6) and Kaufman (1974, Ref. 20).

CROSS REFERENCE
This study also examined overlapping faces in a dynamic scene. See Section 30.1.2.



(a) MEAN JUDGED SLANT=9.3 degrees



(b) MEAN JUDGED SLANT=30.6 degrees

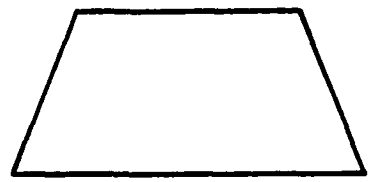
30.2.2 JUDGEMENTS OF STATIC SHAPE (CONT'D)

Figure 30.2.2-3 Interdependence of Judged Slant and Judged Shape.

IMPLICATION
1) Errors in judged slant may cause errors in judged shape.
2) Errors in judged shape may cause errors in judged slant.

REPRESENTATIVE STUDY
Kaiser (1966, Ref. 19)

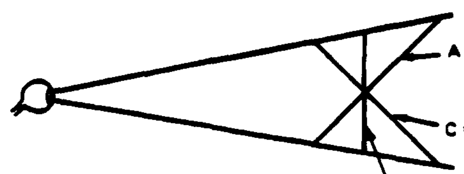
METHOD
Observers judged the shape and slant of a trapezoidal figure. The true slant of the figure was 25 degrees, 45 degrees, or 75 degrees.



RESULTS
The judged slant and the judged shape were closely related. When the slant was misjudged, the shape was also misjudged.

LIMITATIONS
1) Stimuli were static. Results may not generalize to a dynamic scene.
2) Results in different experiments in the literature vary. However, the experiments that appear to be most directly relevant support the implication.

EXAMPLE
The figure illustrates how, in the absence of other cues to shape or slant, an object can be interpreted as having many different shapes, each at a different slant.



SUPPORTING LITERATURE
Beck and Gibson (1955, Ref. 2), and Koffka (1935, Ref. 21)

CROSS REFERENCE
A misperception of the shape of the object, and therefore its slant, may be caused by the tendency to see lines as intersecting at right angles. See Figure 30.2.2-1.

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.2.3 TEXTURE ELEMENT SIZE AND DENSITY

RECOMMENDATION

1) Use an intermediate size and spacing of texture elements.

SUPPORTING ANALYSIS

No adequate data exist to give quantitative guidance. The following qualitative limits are suggested.

The minimal density of the texture elements should be such that (1) the ground surface is sampled often enough to portray the maximum amount of irregularity required, and (2) the texture elements should be seen subjectively as related to each other. Even if these minimal conditions are not met, only two visible elements are required to give relative depth information in a dynamic scene (see Section 32.__ on motion parallax, and Section 31.__ on depth judgments and motion parallax).

The maximal density of the texture elements should be such that the individual texture elements do not overlap to the extent that they merge and form a uniform surface.

Gruber and Clark (1956, Ref. 16) report very limited experimental evidence. With 0.2 degree diameter dots, they found better slant judgments with a 0.9 degree spacing than either a 0.2 or 0.6 degree spacing. Severe methodological problems make the usefulness of this study difficult to evaluate.

LIMITATIONS OF THE RECOMMENDATIONS

1) No adequate experimental evidence exists to support this recommendation.

SUPPORTING ANALYSIS

This recommendation should be considered plausible, but not proven.

CROSS REFERENCE:
The distribution density of texture elements may not be very critical. Phillips (1970, Ref. 27, Figure 30.2.1-3) suggests that the size and shape of texture elements are much more important than their distribution density.

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

30.2.4 VERTICAL OBJECTS IN A STATIC SCENE

RECOMMENDATION	SUPPORTING ANALYSIS
1) Use vertical objects to provide information about ground surface orientation and altitude.	Stevens (1978, Ref. 31) has demonstrated that observers can accurately adjust a line to be vertical to a plane defined by two other intersecting lines in a CRT display. This implies that observers may be able to use that information to make estimates of the orientation of a surface.

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) No experimental evidence exists to support this recommendation.	This recommendation should be considered as plausible, not proven.

CROSS REFERENCE:
See Section 30.1.4 for a discussion of the influence of vertical objects in a dynamic scene.

30.2.5 SHADOWS AND REFLECTIONS IN A STATIC SCENE

RECOMMENDATIONS	SUPPORTING ANALYSIS
1) Shadows and smooth shading should be integrated into the display.	In a static scene, shadows may provide the only cue to the curvature of a surface. Lack of shadows and smooth shading can result in a curved surface being judged as flat. Figure 30.2.5-1 shows an example. See Braunstein (1976, Ref. 6) and Kaufman (1974, Ref 20) for a general discussion.
2) Specular reflections should be included in the display whenever possible.	Specular reflections may give information about the relative orientations and curvature of surfaces.

LIMITATIONS OF THE RECOMMENDATIONS	SUPPORTING ANALYSIS
1) There is no direct supporting evidence.	While there are many examples of the effects of adding shadows and reflections to a scene, there is little quantitative experimental evidence about the effect of shadows. Therefore, the recommendations should be considered as plausible, not proven.

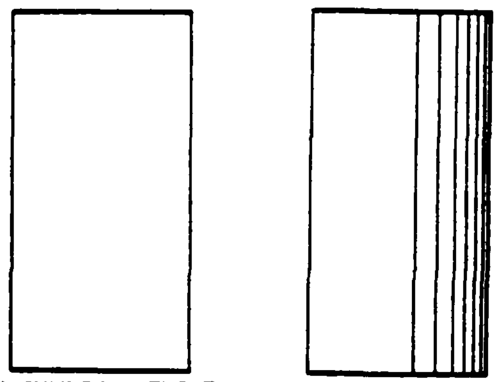
CROSS REFERENCE:
See also Section 30.1.5, which discusses shadows in a dynamic scene.

Figure 30.2.5-1 Judged Shape of a Curved Surface with Smooth Shading.

IMPLICATION
Smooth shading provides strong information about the curvature of surfaces.

REPRESENTATIVE STUDY

Few direct experimental results exist to support the implication, although the importance of shadows is widely acknowledged. Stimulus (a) represents a cylinder with shadows. Other examples of shadowed figures can be found in Braunstein (1976, Ref. 6) and Kaufman (1974, Ref. 20).



(a) CYLINDER WITHOUT SHADOWS (b) CYLINDER WITH SIMULATED SHADOWS

LIMITATIONS

There is little direct evidence. Therefore the result should be considered plausible, not proven.

SUPPORTING LITERATURE

The supporting literature tends to be indirect. Benson and Yonal (1973, Ref. 3), Hess (1961, Ref. 18), Reynolds (1969 Ref. 28), and Yonas, Goldsmith, and Hallstrom (1978, Ref. 33).

CROSS REFERENCE

There is more direct evidence for the implication for a dynamic scene. See Section 30.1.5.
There is more direct evidence for the importance of shadows in depth judgments. See Section 31.__, and Cross and Cross (1969, Ref. 9, Figure 30.5-1).

30.0 JUDGEMENTS OF SURFACE ORIENTATION AND SHAPE

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NOTE: Sections 20.0 - 29.0, 31.0, 32.0, 34.0 - 92.0+ were intentionally excluded from this volume in its present form.

SECTION 33.0 VISUALLY INDUCED SELF-MOTION

SECTION CONTENTS

SECTION 33.0 VISUALLY INDUCED SELF-MOTION

When a scene visible to an observer moves, the motion can be interpreted either as scene motion or self-motion. When flying in an aircraft, scene movement visible through the windscreen is generally interpreted to indicate that the aircraft, and hence the observer, are moving. A theoretically ideal ATD should provide a visual experience like that in a real aircraft. That is, an observer in ATD should experience "self-motion," rather than an impression of a scene moving past a stationary aircraft cockpit. (It must be noted, however, that while it is likely that an individual experiencing self-motion will more effectively learn the complex control actions required during flight under visual flight rules, there is no clear empirical proof.)

In most situations the observer viewing a moving scene first perceives scene motion. If the situation is appropriate, after a short period of a fraction of a second to several seconds, the observer will perceive a mixture of scene and self-motion. This may then progress to exclusive self-motion. The sensation of self-motion may persist for several seconds after the scene stops moving or is no longer visible.

The sensation of false motion because of scene motion was once known as "railroad illusion" because it was often experienced while seated in a motionless railroad car as another nearby railroad car began to move. It is now commonly referred to as "vection," or "visually induced illusory self-motion."

Recent research has identified some parameters involved in visual induction of self-motion. A summary of the area, including vestibular as well as visual topics, and historical review, are provided by Dichgans and Brandt (1978, Ref. 3). (Vestibular function is covered in Section 61.0 to 66.0) More common laboratory methods of induction are illustrated in Section 33.1, and data relevant to ATD design that have been obtained in this type of research are summmarized in Sections 33.2 through 33.6 Topic areas addressed include:

1) Density of image detail - How many image details should be present and how close together should they be to induce self-motion most effectively? Section 33.2)

2) Image sharpness - Does blur in the image interfere with the induction of self-motion? (Section 33.2)

3) Field of view - How large a field of view is needed to obtain the maximum sensation of self-motion? (Section 33.3)

4) Location of moving image - What is the relative importance of different portions of the visual field for inducing self-motion, particularly the peripheral versus the central visual field? (Section 33.3)

5) Apparent image distance - How is the apparent velocity of self-motion affected by the apparent distance to the moving scene? (Section 33.4)

6) Effect of stationary details - To what extent do stationary image details (such as raster lines) interfere with the induction of self-motion? (Section 33.5)

SECTION 33.0 VISUALLY INDUCED SELF-MOTION

33.1 TEST CONFIGURATIONS

Most research on the visual induction of self-motion involves one of the test configurations summarized in Figure 33.1-1 below. The relevant physical parameters are summarized in the experiment descriptions in Sections 33.2 through 33.6.

An important issue not adequately addressed in any of the available research on induction of self-motion is the importance of the setting in which the test is performed. For example, an observer is probably more likely to perceive a moving visual scene in terms of the intended self-motion in an aircraft simulator incorporating a realistic, continuously moving external scene than when viewing the simple moving pattern of colored dots or stripes in a laboratory setting. All of the available research utilized the latter type of experimental setting. As a result, the results must be extrapolated to the more complex aircraft simulator situation with care.

Another possibly important aspect of the experimental setting is the physical support provided the observer. In most but not all the experiments on illusory self-motion summarized in Sections 33.2 to 33.7, the observer was seated or standing on a mechanism that allowed motion of the type that was induced by the moving scene. Although many displays have been demonstrated to provide a strong sensation of self-motion even though the observer knew that such motion was not possible, there is no known documentation to establish whether the sensation is reduced if the observer knows that motion is physically impossible.

Several methods are used to measure the effectiveness of a particular test situation or display for inducing self- motion. These include:

1) Latency from first viewing the moving scene until self-motion occurs.

2) Duration of the"afteraffect," or period of apparent self-motion after the scene stops moving or is no longer visible.

3) Judged velocity of self-motion to front or rear (c) in Figure 33.1-1) or judged velocity of self-rotation (a) in Figure 33.1-1). The observer may report this judgment verbally or by adjusting a rotary control or a lever to a position judged to be equivalent to the velocity. This judgment is usually made against a reference standard. In a study of field of view, for example, the standard would typically be the maximum available display field.

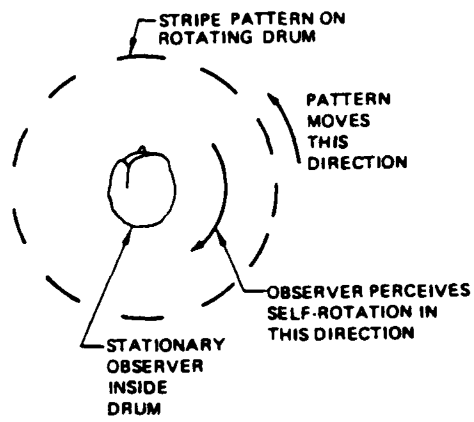
4) Judged tilt (b) in Figure 33.1-1). The observer usually reports this by adjusting a line in the center of the moving display to apparent vertical or horizontal.

33.1 TEST CONFIGURATIONS (CONT'D)

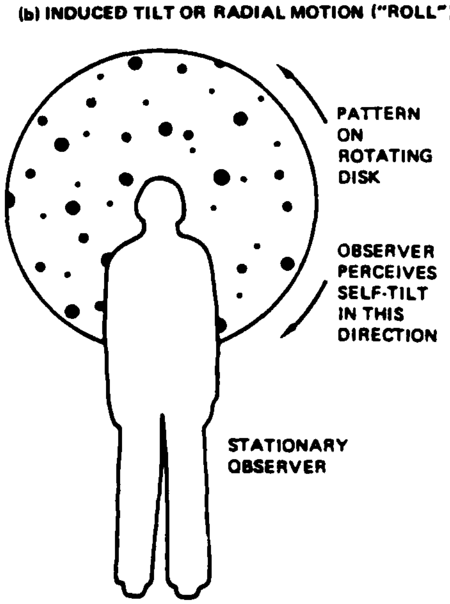
Figure 33.1-1 Vection Test Configurations

The three most common methods for studying induced self-motion are illustrated here. Circular vection is comparable to forward motion in an aircraft, while linear vection is comparable to forward motion. Induced tilt is comparable to roll, with the major difference that the maximum tilt induced in the upright test observer in most laboratory studies is about 15 to 20 degrees. However, even with this limitation, it is probable that the stimulus conditions most effective in inducing tilt in a laboratory will also contribute most to a sensation of roll in a simulator.

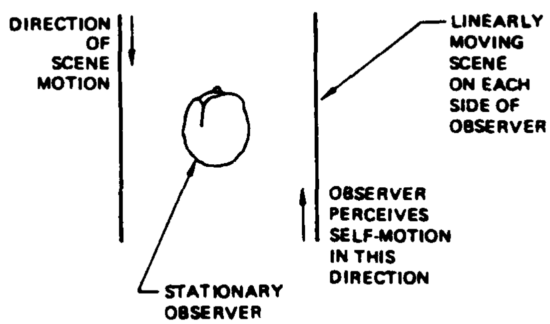
(a) CIRCULAR VECTION ("YAW")



(b) INDUCED TILT OR RADIAL MOTION ("ROLL")



(c) LINEAR VECTION



SECTION 33.0 VISUALLY INDUCED SELF-MOTION

33.2 IMAGE CONTENT AND QUALITY

RECOMMENDATIONS

1) Consider the contribution of the quantity of edges provided when specifying a scene intended to induce self-motion.

SUPPORTING ANALYSIS

In the one relevant experiment (Figure 33.2-1), more edges induced more self-tilt, but increasing the number of edges beyond 20 small circles in a 132 degree field induced only a very small additional self-tilt. This suggests that not very many edges are required for a scene to be effective, but it does not allow setting quantitative limits. A few large objects, subtending perhaps 4 to 8 degrees, are probably more effective than twice that many much smaller objects.

LIMITATION
A problem in attempting to set a quantitative limit is that there is currently no meaningful metric for scene content in an ATD display.

CROSS REFERENCE
Consider peripheral visual acuity for moving objects (Sections 22.__ and 32.__) when establishing the size of scene details to induce self-motion.

2) Do not provide a sharp image in an ATD visual display simply to induce self-motion. NOTE: A sharp image may be required for other reasons.

The data in Figure 33.2-2 show that self-motion can be effectively induced with a scene that is extremely blurred. Apparently, as long as it is above threshold visibility, any pattern can induce self-motion. It is not obvious how to extrapolate from the scene content and blur of that study to typical ATD scenes. Note: A sharp image will not interfere with the induction of self-motion and may be required for other functions such as recognizing objects for ground surface orientation, target acquisition or navigation.

CROSS REFERENCE
Consider peripheral visual acuity for moving objects (Sections 22.__)when establishing the sharpness of scene details to induce self-motion.

3) Avoid changes in the spatial frequency of edges in an ATD visual scene beyond those required for cultural realism. (For example, the roads in an urban area will generally be closer together than in a rural area.)

A reduction in the spacing between scene edges will probably cause a sensation of greater forward velocity during low level flight. There is no clear experimental evidence on this point, but it is supported by observations in an ATD (Rife, 1980, Ref. 12) and by a study by Lestienne, Soechting and Berthoz (1977, Ref. 9), where a higher spatial frequency image moving past a standing observer as is illustrated in apart (c) of Figure 33.1-1 yielded a greater postural control response.

33.2 IMAGE CONTENT AND QUALITY (CONT'D)

Figure 33.2-1 Induced Tilt as a Function of Image Density.

IMPLICATION

The amount of tilt induced by a rotating image increases, within limits, with the number of details in the image.

STUDY

Brandt, Wist and Dichgans (1979, Ref 5.

METHOD

Observers adjusted a line to apparent vertical while viewing high contrast colored spots on a rotating disk, as in (a) and in Figure 33.1-1(b).

RESULTS.

See (c)

LIMITATIONS

Image content was in terms of the num- of high-contrast constant-size spots; this parameter does not translate easily to typical CIG scene parameters such as number of edges or faces.

CROSS REFERENCE

The impact of stationary scene details was also tested in this study. See Figure 33.5-1.

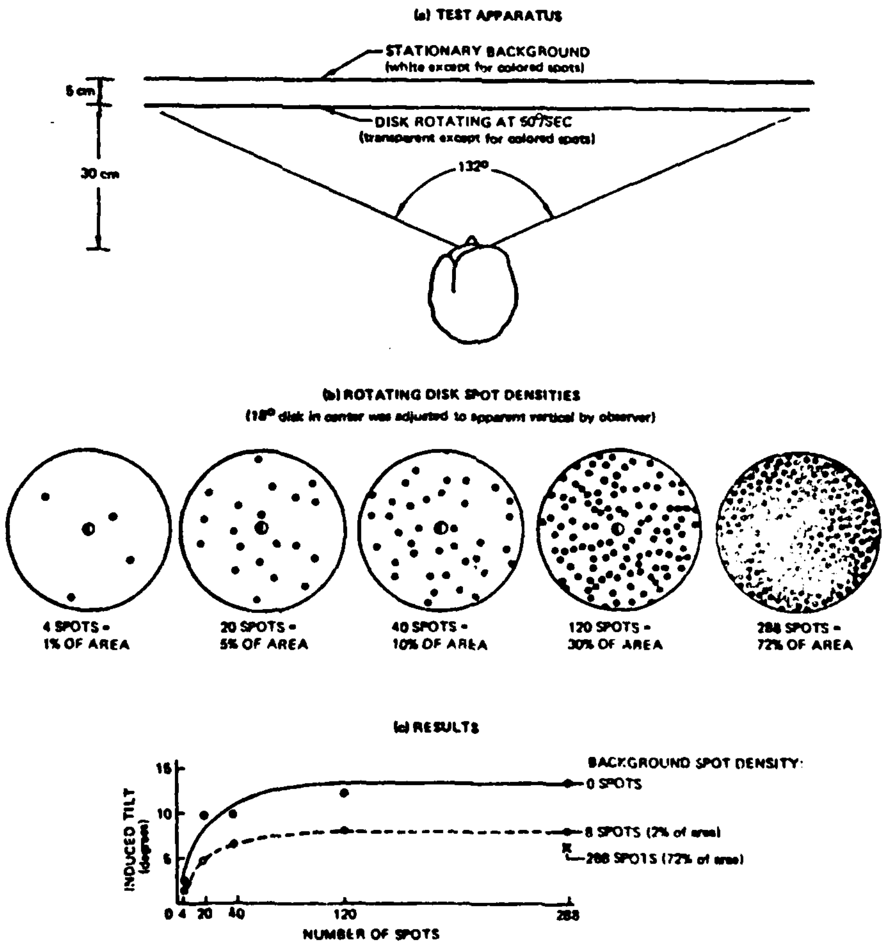
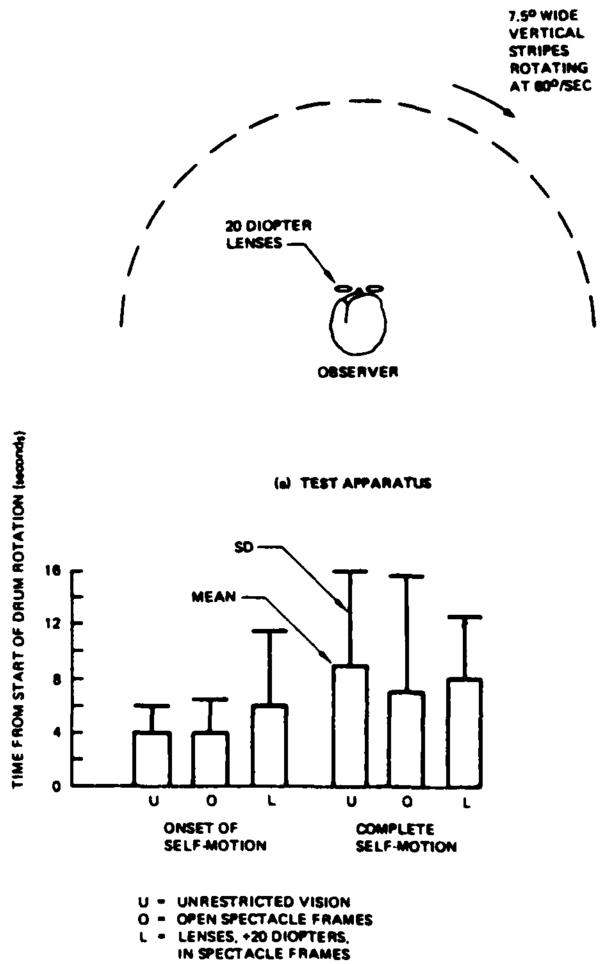


Figure 33.2-2 Induction of Self-Motion by a Blurred Image

IMPLICATION
Self-motion can be effectively induced by an extremely blurred image.

STUDY
Leibowitz, Rodemer, and Dichgans (1979, Ref. 8)

METHOD
<u>Apparatus</u>: Drum, 1.4 meter diameter, containing black and white vertical stripes 7.5 degrees wide, rotating at 60 degrees per second. Stripe contrast was 88 percent. Luminance of the white stripes was 16.6 candelas per square meter. The observer sat in a fixed chair and viewed the stripes: (U) with no restrictions, (O) through a pair of spectacle frames containing no lenses, and (L) through the same frames containing 20 diopter plus lenses. These lenses produced gross blurring of the stripes. A mask prevented viewing of stripes outside the area of the lenses.
<u>Procedure</u>: With drum rotating, observer opened eyes and reported when self-motion just started ("onset") and when the drum appeared to stop and the experience was exclusivly of self-motion ("complete").
<u>Observers</u>: Fourteen.



(a) TEST APPARATUS

(b) RESULTS

RESULTS
The blur introduced by the lenses caused little if any reduction in the induction of self-motion. See (b).

LIMITATION

1) The absence of an effect due to blur observed in this experiment may not extend to extremely low image velocities. At much lower velocities, near the threshold for detection of motion, blur interferes with the ability to detect motion. (Ref. 8)
2) Quantitative limits on blur for other shape and sizes of image details cannot yet be established.

33.3 LOCATION AND EXTENT OF AREA CONTAINING IMAGE DETAILS

RECOMMENDATION

To induce self-motion most effectively, place the greatest emphasis on providing image details in the mid-periphery of the observer's visual field; the best location is about 45 degrees from the line of sight.

ANALYSIS

This recommendation applies only if some limitation is necessary on the amount of image detail or the size of the display field. This might occur, for example, when only a portion of of the aircraft field of view is to contain an image display, or when the number of image details is severely limited by computations capability. It does not apply to that portion of an ATD display intended for functions requiring higher resolution such as target acquisition or observing navigation checkpoints.

LIMITATION

The experimental results summarized in this section are not in total agreement. The data in Figures 33.3-1 and -2 suggest an optimum location in the neighborhood of 45 degrees from the observer's point of fixation, while Figure 33.3-3 suggests a somewhat more central location.

33.3 LOCATION AND EXTENT OF AREA CONTAINING IMAGE DETAILS (CONT'D)

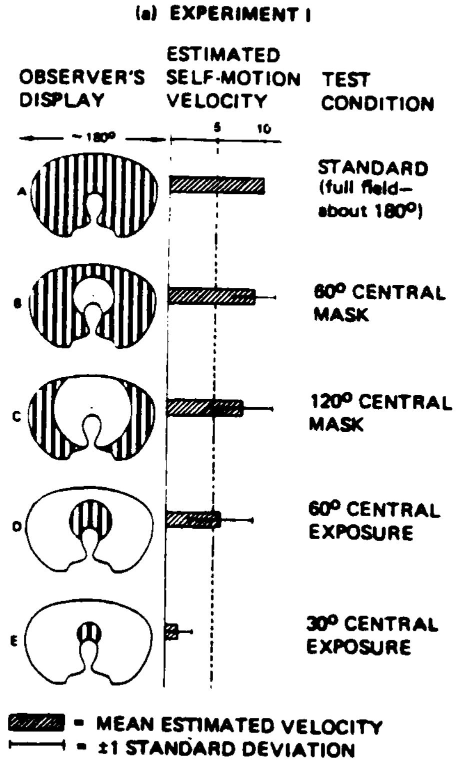
Figure 33.3-1 Display Field Area and Velocity of Induced Self-Motion.

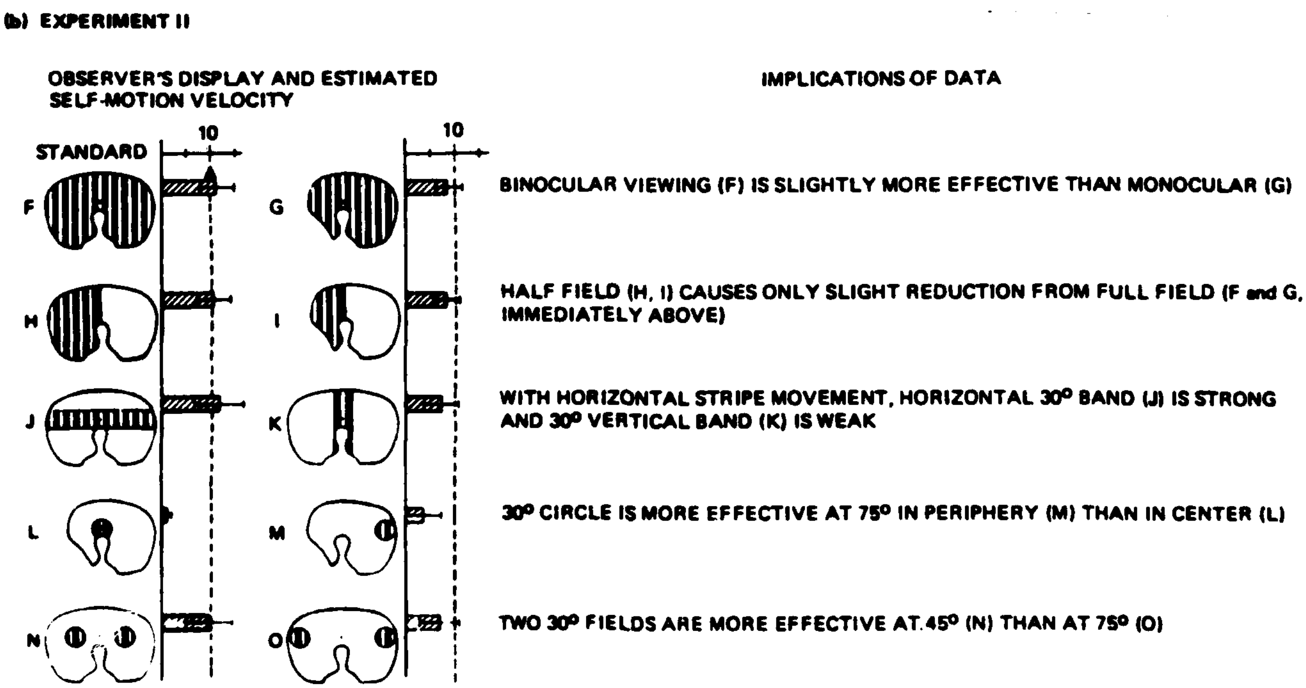
IMPLICATION
Mid-periphery of the visual field is more effective than either the central portion or extreme periphery for inducing self-motion.

STUDY
Brandt, Dichgans and Koenig (1973, Ref. 4)

METHOD
Apparatus: Drum, 1,5 meter diameter, containing black & white vertical stripes 7 degrees wide, rotating at 60 degrees/second. Observer sat in rotatable chair in center. Portions of display field were obscured with opaque black mask; figure shows each as it would appear from behind observer.
Procedure: Observer estimated self-motion velocity relative to a standard condition, (A) in Experiment I and (F) in Experiment II, that had an arbitrary value of 10.
Observers: A total of 20 in the two studies summarized here.

RESULTS
Experiment I: Periphery was more effective than central visual field.
Experiment II: See comparisons in (b).





33.3 LOCATION AND EXTENT OF AREA CONTAINING IMAGE DETAILS (CONT'D)

Figure 33.3-2 Imagery Eccentricity and Induced Tilt

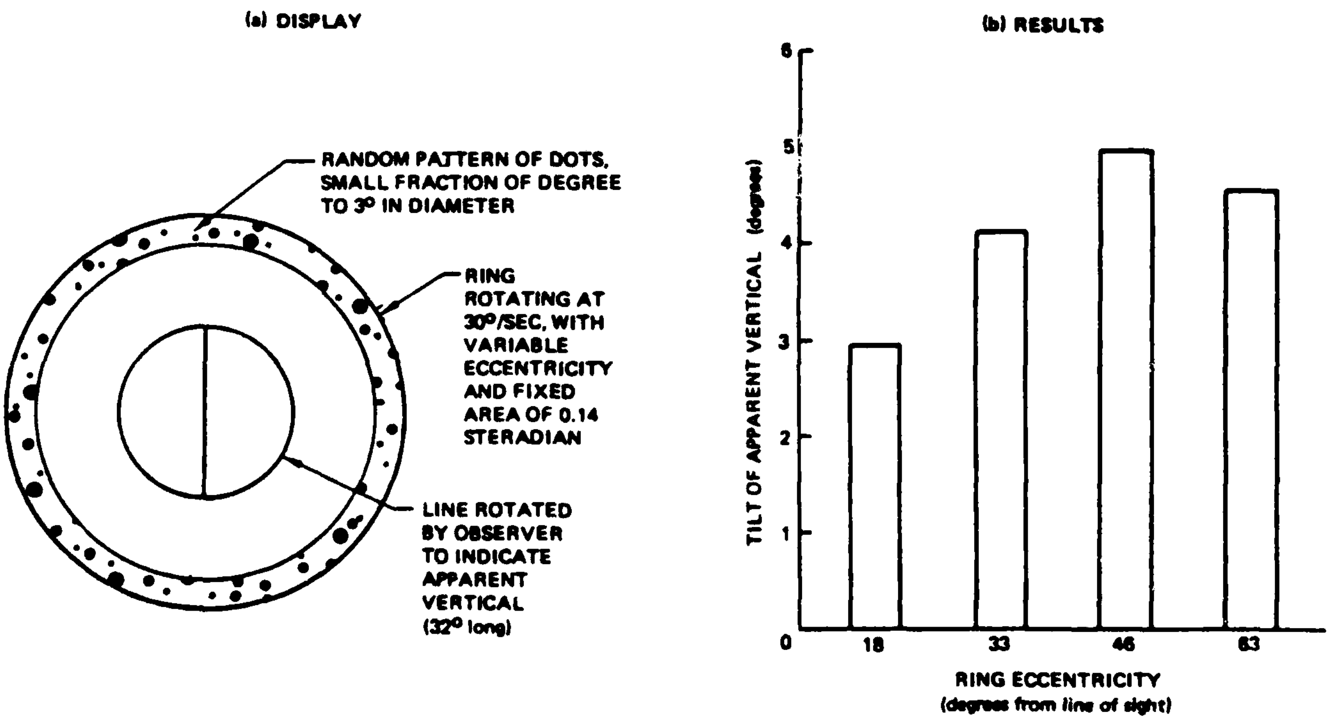
IMPLICATION
The effectiveness of a moving image of constant subtended area for inducing a sensation of body tilt is greatest in the midperiphery of the visual field, at an angle of about 48 degrees from the line of sight.

STUDY
Held, Dichgans and Bauer (1975, Ref. 6)

METHOD
Observers adjusted a line to apparent vertical while viewing a ring-shaped portion of a rotating disk monocularly through a positive lens. Image quality for the extreme ring eccentricity, 63 degrees from the line of sight, was poor.

RESULTS. See (b).

LIMITATIONS
(1) Although disk rotation velocity around the disk center was constant, image velocity relative to the observer increased with ring eccentricity and this increase in velocity may have induced more tilt.
(2) Image blurring caused by the poor lens quality at 63 degrees might have reduced the tilt. The data in Figure 33.2-2 show that considerable blur does not interfere with the induction of self-motion, but that study is not directly comparable because the image details were larger and because there is no way of relating the amount of blur in the two studies.



33.3 LOCATION AND EXTENT OF AREA CONTAINING IMAGE DETAILS (CONT'D)

Figure 33.3-3 Image Area and Induced Tilt

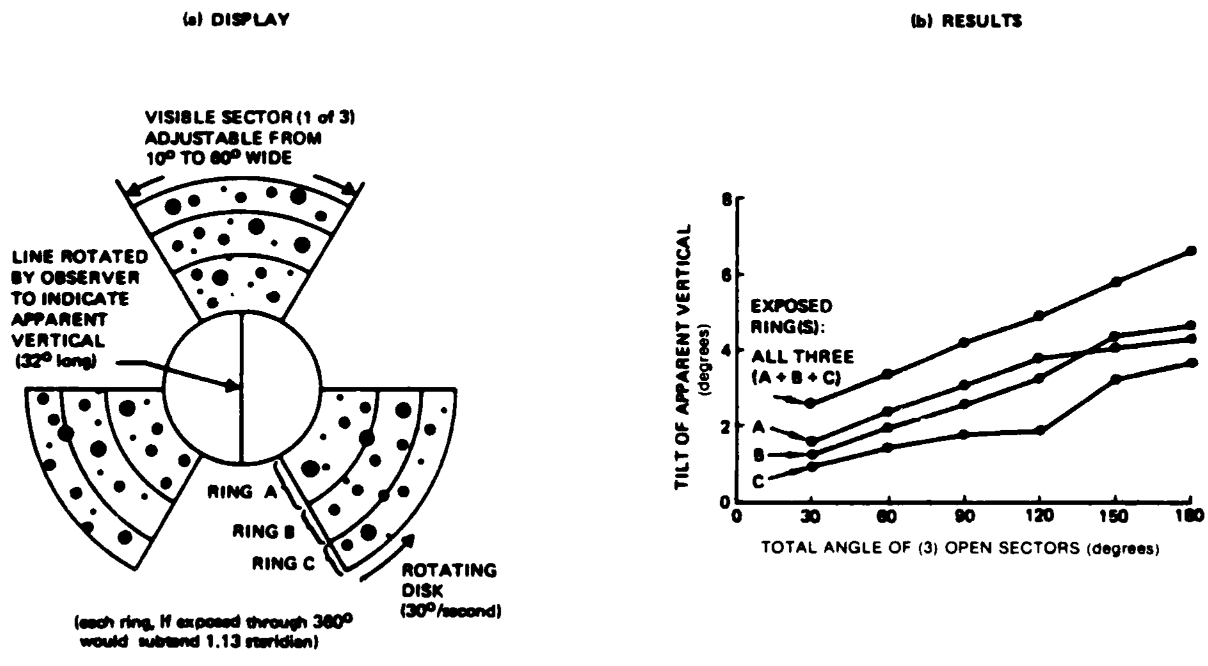
IMPLICATION
(1) An increase in the scene area filled by a rotating image increases the amount of induced tilt.
(2) Amount of induced tilt does not always increase with image eccentricity.

STUDY
Held, Dichgans and Bauer (1975, Ref. 6)

METHOD
Observers adjusted a line to apparent vertical while viewing a portion of a rotating disk monocularly through a positive lens. (Same apparatus as Figure 33.3-2.) Masks limited viewing to three variable-width sectors of three equal-area rings.

RESULTS
(1) Induced tilt increased with area visible.
(2) In contrast to Figure 33.3-1 and -2, induced tilt was slightly less for the more peripheral image areas.

LIMITATIONS
Generally the same as Figure 33.3-2, which involved the same apparatus.



33.4 IMAGE DISTANCE

RECOMMENDATION

Maximize accuracy of self-motion perception by providing an image that yields an effective perception of portrayed scene distance.

CROSS REFERENCE

1) Distance perception in general is discussed in Section 31.0 and, for the special case of stereopsis, in Section 29.__.

(2) Inaccurate perception of distance can cause another problem by distorting the perceived motion of other objects such as a distant aircraft; this topic is discussed in Section 31.__.

MODEL

An empirical model for the effect of apparent image distance on self-motion velocity is provided by the experiment summarized in Figure 33.4-1:

M = K A D, where
M = perceived velocity of induced self-motion
K = constant of proportionality
A = angular velocity of scene relative to observer
D = perceived distance to scene.

This model is valid in a general sense, and in the study in Figure 33.4-1 was quite effective, accounting for an average (median) of about 90 percent of the variance of reported self-motion velocity. However, quantitative application is complicated by several factors.

SUPPORTING ANALYSIS

Displayed motion velocity of a CIG image is computed from the geometric relationships of the scene being simulated. The data in Figure 33.4-4 below suggest that if the scene is perceived as being closer than the distance used to compute the scene. the perceived velocity of self-motion will be reduced. Although not empirically proven, it is reasonable to assume that a major reduction in the sensation of self-motion will reduce simulator training effectiveness for many flight maneuvers.

33.4 IMAGE DISTANCE (CONT'D)

(1) The constant of proportionality, K, has been measured in only one experiment (Figure 33.4-1) using only one method of changing perceived distance, and even within the single method used in Figure 33.4-1, it varied among individuals from 0.45 to 1.42.
(2) Perceived distance, D, is difficult to quantify in a meaningful fashion. For example, in the study of perceived size and distance, an observer may report a value for estimated distance quite different from that indicated by the effect of distance on judged size. (See the discussion of the impact of perceived distance on perceived size in Section 31.__.)

Figure 33.4-1 Perceived Distance and Velocity of Self-Motion.

IMPLICATION
For a constant angular image velocity, the velocity of induced self-motion varies directly with the apparent distance to the image.

STUDY
Wist, Diener, Dichgans, and Brandt (1975, Ref. 12)
METHOD
Apparatus: Drum, 1.6 meter diameter, containing black and white vertical stripes 7 degrees wide, rotating at 80 or 130 degrees per second. Observers sat in fixed chair in center. Pulfrich effect (Ref. 11) was used to increase or decrease the apparent distance to the drum.
Procedure: Observer estimated both distance to striped surface and velocity of apparent self-motion, using the unmodified 0.8 meter distance as a standard with an arbitrary value of 100. Larger values implied greater distance or greater apparent velocity.
Observers: About 11.
RESULTS
Estimated velocity of self-motion closely matched estimated distance.

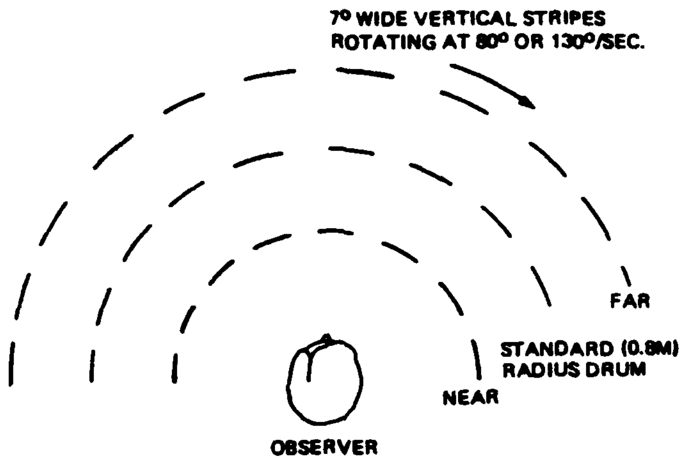
SUPPLEMENTARY EXPERIMENT
A brief supplementary study was performed to assess the generality of the Pulfrich effect for changing image distance. Two methods were used: (1) The rotating surface was moved closer by fixation on a closer point in space, and (2) It was moved closer by using prisms to increase eye convergence. In both cases the perceived velocity of self-motion decreased, thereby providing additional support for the results summarized in the figure.

CROSS REFERENCE
These results parallel many of the results for perceived distance and the perception of motion discussed in Sections 31.__ and 32.__.

SECTION 33.0 VISUALLY INDUCED SELF-MOTION

33.5 CONFLICT BETWEEN MOVING AND NON-MOVING IMAGE DETAILS

(a) TEST SETTING



(b) RESULTS

	80°/SEC ROTATION				130°/SEC ROTATION			
	PERCEIVED DISTANCE		PERCEIVED VELOCITY		PERCEIVED DISTANCE		PERCEIVED VELOCITY	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
NEAR	81	7	78	13	64	11	70	16
STANDARD	100		100		100		100	
FAR	120	10	120	11	137	20	126	12

RECOMMENDATION

Minimize stationary details such as CRT raster lines and CRT faceplate defects in a scene intended to induce self-motion.

CROSS REFERENCE

Section 23.__ can be used to help determine the size and contrast of stationary image details that will be visible.

SUPPORTING ANALYSIS

The inhibitory effect of stationary scene details is potentially large and increases with the number of stationary details present (Figure 33.5-1). The relative distance to moving and stationary scene details has an impact on the amount of inhibitory effect (Figure 33.5-2) but the exact nature of this impact is not clearly established. Stationary details more distant than the moving scene appear to be the most disruptive but are least likely to occur in an ATD.

33.5 CONFLICT BETWEEN MOVING AND NON-MOVING IMAGE DETAILS (CONT'D)

Figure 33.5-1 Inhibition of Induced Tilt by Stationary Image Details

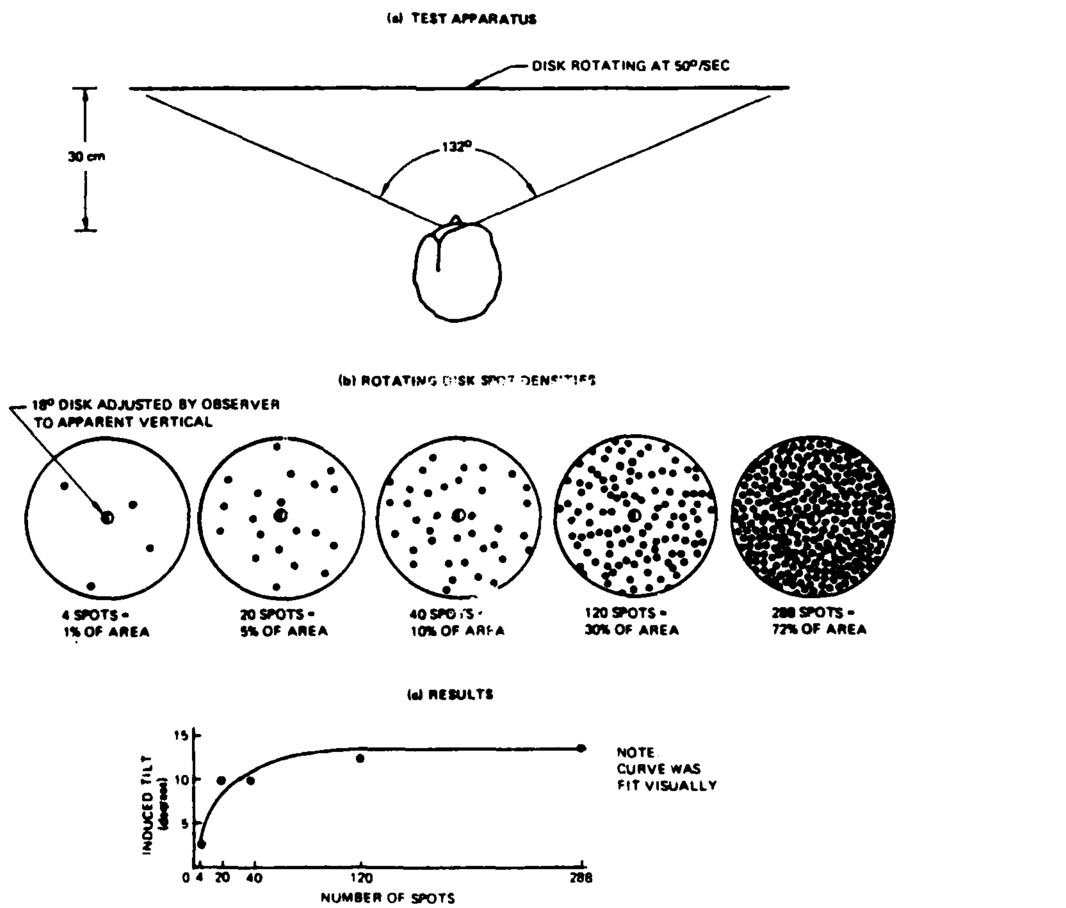
IMPLICATIONS
Stationary image details located slightly more distant than a moving image inhibit the sensation of tilt normally induced by the moving image.

STUDY
Brandt, Wist and Dichgans (1975, Ref 5.

METHOD
Apparatus: The observer viewed high contrast red, yellow and blue spots on two planes, the nearer one being transparent and rotating at 50 degrees per second. Each spot filled .25 percent of the display field. Spot densities for the rotating plane are shown in (b). The stationary plane contained either 0, 8 or 288 spots.

Procedure: Observers adjusted a line to apparent vertical.

RESULTS
Induced tilt was reduced by 8 stationary spots filling 2 percent of the display area. (See figure.) When 288 stationary spots were present, filling 72 percent of the display area, tilt was induced by the 288 spot rotating image but not by rotating images containing fewer spots.



33.5 CONFLICT BETWEEN MOVING AND NON-MOVING IMAGE DETAILS (CONT'D)

Figure 33.5-2 Inhibition of Induced Rotary Self-Motion by Stationary Image Details

IMPLICATIONS

Stationary image details interfere with the induction of self-motion by a moving image. This interference is greatest if the stationary image is more distant than the moving image.

STUDY

Brandt, Wist and Dichgans (1975, Ref 5)

METHOD

Apparatus: Drum, 1.6 meter diameter, containing black and white vertical stripes 7 degrees wide, rotating at 85 to 100 degrees/second. Observer sat at center. Pulfrich effect (Ref. 11) was used to move the rotating image closer, to 56 centimeters, in some test conditions. A fixed pattern of vertical stripes could be placed at 32, 56 or 80 centimeters. Fixed stripe width was presumably 7 degrees except for one condition in Experiment A.

Procedure: Experiment A - Observers indicated when self-motion was perceived after image rotation started. Experiment B - Observers continuously adjusted a control to indicate apparent velocity of self-motion over a 60-second trial.
Observers: Five.

RESULTS

Experiment A:
1) A fixed image more distant than the moving image interfered with induction of self-motion.
2) Interference was greatest when the stripes in the fixed and moving images were the same apparent size.
3) However, a fixed image closer than the moving image did not interfere.

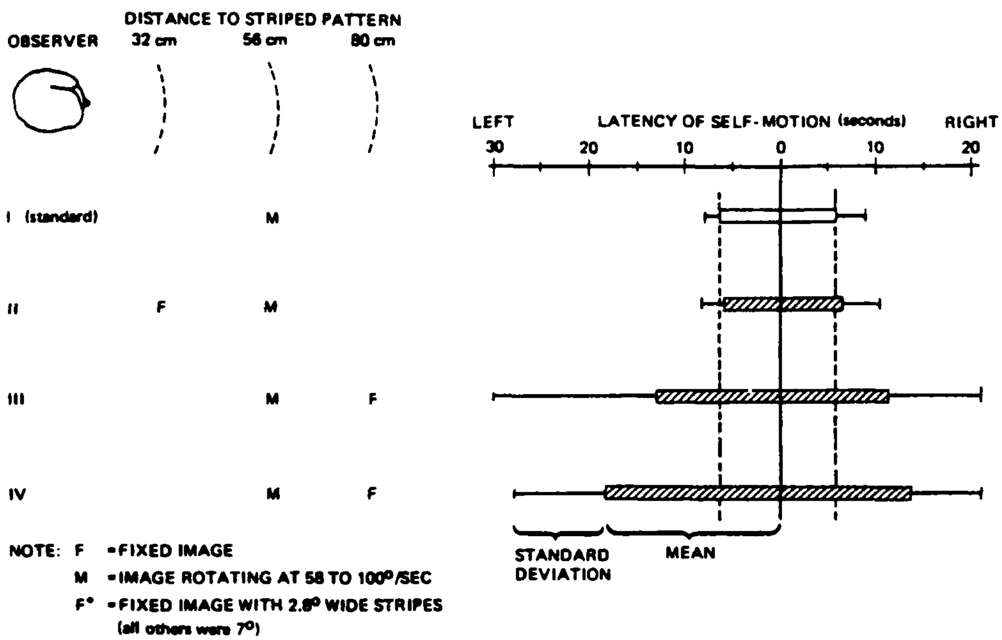
Experiment B:
1) A fixed image interfered with the induction of self-motion.
2) This interference was much greater when the fixed image was more distant than the moving image than when it was closer. 3)When the fixed and moving images were at the same distance the amount of interference averaged over the five observers was small, but both the recordings of perceived velocity controls and the standard deviations of the control settings showed that the amount of interference was large for some observers but not for others.

LIMITATIONS

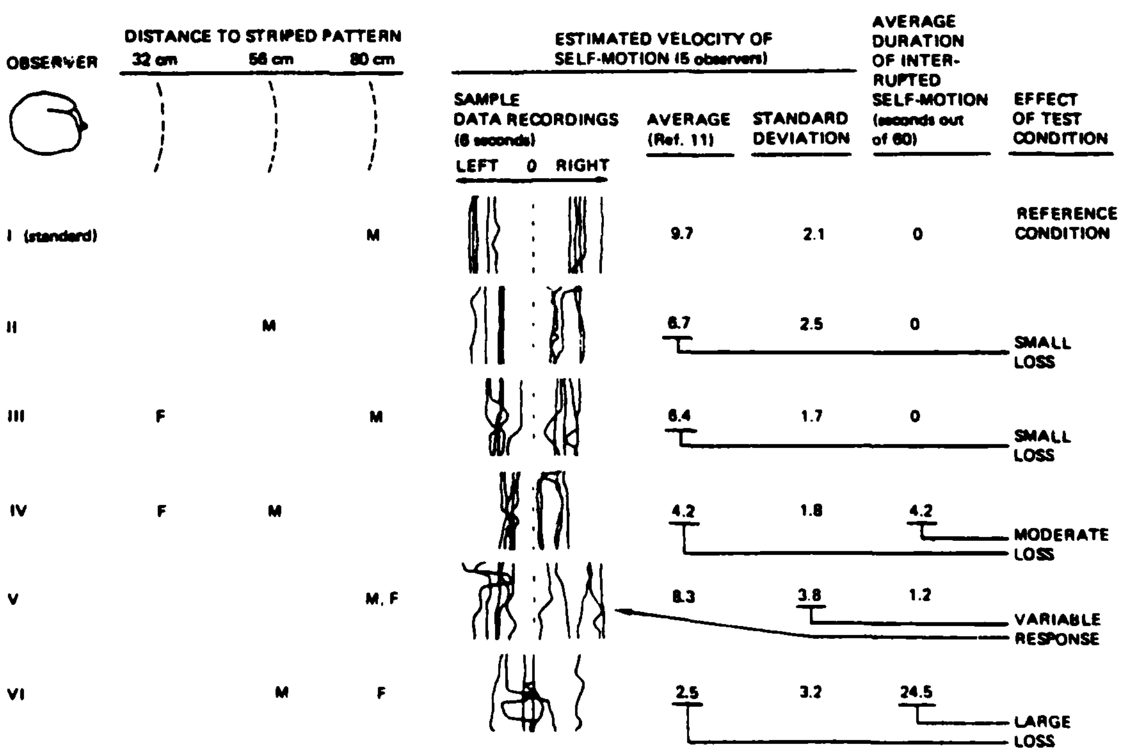
The black and white stripes were equal in width and, with the exception of one condition in Experiment A, the fixed and moving images were apparently equivalent in size as viewed by the observer. Hence, given the stripe width of 7 degrees and velocity of 85 to 100 degrees per second, the fixed and moving patterns presumable coincided to produce a totally black display 6 to 7 times a second. It is not clear exactly how well data from this type of display can be extrapolated to questions such as the impact of raster line visibility in a CRT display used in an ATD.

33.5 CONFLICT BETWEEN MOVING AND NON-MOVING IMAGE DETAILS (CONT'D)

(a) EXPERIMENT A – LATENCY OF SELF-MOTION



(b) EXPERIMENT B – ESTIMATED VELOCITY OF SELF-MOTION



33.6 LATENCY OF SELF-MOTION

Even though the latencies measured in most self-motion studies are greater than in operational flight, the results of these studies are generally applicable to ATD design.

A potential objection to the application of vection research data to ATD design is that vection studies typically report latencies of two to six seconds from the beginning of scene movement until the observer reports self-motion. These values are longer than can be tolerated in operational situations such as high-speed nap-of-the-earth flight. Hence the question arises whether available vection data can be applied to the design of devices to train for such situations.

The large latencies in vection research appear to be due at least in part to how the experiments were performed. Latencies to changes in velocity, rather than to the change from no motion to motion used in most of the studies cited in Section 33.0, are much smaller (Leibowitz, et al, 1980, Ref. 7). However, no measurements have been published for any situations except oscillatory motion, where the scene alternates between motion in one direction and then in the reverse direction. For this type of experiment with linear scene movement (part (c) in Figure 33.1-1), phase lag between scene movement and the observers's reported self-motion increases with oscillatory frequency until, at about 0.8 Hz, the observer is practically in opposite phase with the image (Berthoz, Pavard, and Young, 1975, Ref. 2).

Even though this type of experimental situation is a little more like flight than the initially stationary scene used in most experiments, the differences are still too large to make meaningful application of the data to a flight situation.

The one experiment summarized in this section (Figure 33.6-1) shows that the long latencies in many experiments are also due in part to the type of self-motion sensation being measured. The physiological parameter measured in this experiment, electrical activity in the observer's ankle muscle, provides evidence that response actually can occur within 0.15 seconds after scene movement starts.

In summary, the absolute value of self-motion latency appears to depend on how compelling the test situation is and on how latency is measured. Even though the experimentally measured latency may be larger than in actual flight situations, the relative superiortiy of different scene features is likely to be the same in flight as in the experiment. Hence it is reasonable to apply the data summarized in Section 33.0 when evaluating display configurations. It is probably not safe to use these experimental results to estimate absolute values of response latency in more realistic situations.

33.6 LATENCY OF SELF-MOTION (CONT'D)

Figure 33.6-1 Visual Contribution to Rapid Motor Responses During Postural Control.

IMPLICATION

Visual cues can contribute to an individual's response to movement within 100 to 150 milliseconds of the beginning of the movement.

STUDY

Nasher and Berthoz (1978, Ref. 10)

METHOD

Rationale: A standing observer in a normal viewing situation has both visual and vestibular cues to body sway. Both types of cues can serve to control the corrective changes in in muscle tension required to maintain posture. By observing the changes in leg muscle tension that occur either with or without visual cues, it is possible to identify the contribution of these cues.

Apparatus: Observer stood on a cart that could be translated to observer's rear. The observer's visual field was provided by a box that could be moved relative to the cart to stabilize scene motion during head movement.

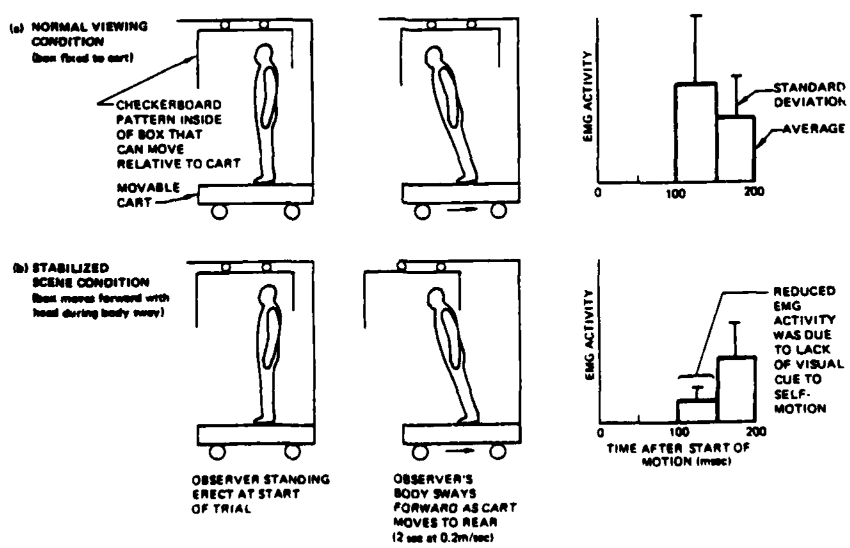
Procedure: Electromyographic (EMG) activity of ankle extensor muscles was recorded as cart was translated. In the normal visual cue condition (a in figure) the visual scene was fixed to the cart and provided normal visual cues. In the stabilized condition (b in figure), the visual scene tracked the observer's head position, eliminating the visual cue to sway.

RESULTS

In the absence of visual cues to body sway, the EMG activity that normally occurs 100 to 160 milliseconds after start of platform motion is drastically reduces.

LIMITATIONS

This study demonstrates the contribution of visual cues to the perception of self-movement only in the negative sense that removal of visual cues eliminated a normal physiological response to visual cue movement. Measurement of EMG activity in response to visual scene movement with no cart movement would have provided better direct evidence of the contribution of visual cues.



SECTION 33.0 VISUALLY INDUCED SELF-MOTION

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